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British Trade and Industry

THE year just closing has been a very anxious one for Britain. The sterling-dollar unbalance has continued to cause anxiety, and, despite the fact that some progress has been made in overseas trade, her economic position is precarious. It should be remembered that, during this period, there has been practically full employment; what would happen if world demand should slacken is too serious to contemplate, since she has little or no resources to bear the effects of a prolonged lapse in trade.

During the whole of the year all concerned with British trade and industry have been urged to greater effort in order to increase exports, particularly to dollar countries, but the response cannot be regarded as startling. Since 1947 progress in production can be divided into three distinct periods. In the first period, up to the end of 1947, exports and current consumption were rising to between 16 and 19% above the 1946 average. The second period ran until the first quarter of this year. Over those fifteen months production went on rising at a slightly lower annual rate of about 6-7% while consumption of goods and services at home flattened out, allowing exports to go on rising at an undiminished rate to reach a peak of 56% above 1938. Then, with the second and third quarters of this year, production was still rising at much the same annual rate as before, but the volume of exports falling back to only slightly above the level of a year earlier, and consumption showing signs of rising more sharply than a year before. The October and November returns do show a slight improvement, exports being approximately £156 million and £160·4 million, respectively, the latter showing an advance of £0·4 million on the previous record established in March this year. It is noteworthy that the excess of imports over exports was £35·2 million, the lowest since March.

It will be noted that, until the second quarter of this year, a stable level of consumption was enabling the benefits of steadily increasing production to flow into exports and into the rebuilding of Britain's physical assets. It is because that flow has not yet proved full enough, and because the home demand for goods is itself rising, that the production increases so far achieved are not enough. The employment index has been fairly stable at a level about 2% higher than in 1948. With an annual increase in production of 6-7%, the productivity rise is approximately 4-5%, twice the rate of increase which is generally claimed as having occurred in the years just before the war, although the conditions were very different from what they are to-day, certainly

there was not the same need to export at the expense of home consumption. However, the war interrupted the normal rate of improvement and Britain has since had to make up for six sterile years—at least as far as peacetime industries were concerned—during which she sacrificed almost all her overseas assets and became a debtor nation. Thus the present increase is much less than the nation needs.

With the beginning of the last quarter Britain devalued sterling with the object of assisting manufacturers to sell in dollar markets, but it will be

We take this opportunity of extending to all
Readers Sincere Good Wishes for Christmas
and the coming New Year.

appreciated that, since a considerable proportion of her imports come from dollar countries, the cost of imports will tend to increase, and an increase in exports will be necessary to counter this tendency. The question arises, therefore, whether Britain can provide the total quantity of goods required for that export as well as her current consumption levels. The immediate effect of devaluation seems to be overloaded order books and longer delivery dates rather than any marked increase in shipments. This problem is being experienced in a wide range of engineering products. Of course, in many of these cases, there are obvious difficulties in the way of rapid increase in output. It must be kept in mind also that most engineering firms are already producing to full capacity, for this reason there is pressure on manufacturers to give priority to orders for dollar markets, even though this may mean considerable rearrangement of work as well as disappointing old-established customers.

It is very doubtful indeed whether this latter expediency will be a profitable one in the long run, trade associations with many overseas countries have been built up through many fluctuating years and customers have come to rely on the quality of the products supplied by British firms. It is not surprising that many manufacturers are not taking kindly to the diversion of their products to markets with which they are not familiar. Probably a saner method would be to concentrate more on increased productivity, and one method of assisting this would be to equip home industries with some of the machinery scheduled for shipment overseas. It is true, of course, that during the last few years there has been intense mechanisation of the coal mines without appreciable increase in the total or individual output; much still requires to be done before pre-war quantities and qualities are reached. Fortunately the introduction of new and the modernisation of existing equipment in the iron and steel industry is continuing to enable the industry to make an outstanding contribution to the recovery programme. Production of steel ingots and castings in November was at an annual rate of 16,358,000

tons compared with an annual rate of 15,760,000 tons in November of last year, and it seems that the target set for this year will again be exceeded.

Although new developments in materials have been few in number there have been considerable developments in other sections of the metallurgical industry, not only in assisting and serving industries to reach their respective targets, but in supplying materials that meet more exacting service conditions. Elsewhere in this issue some of the more promising developments are reviewed which will be found to indicate a high order of technical progress. However, the need for the more rapid assimilation of industrial and technical progress was never more pressing than to-day, in order that it may be applied to increase production or improve products and assist the more rapid economy recovery, with a view to removing the cause of the present anxiety.

Steel Founders' Productivity Convention

WITH the object of studying American production methods and comparing them with those operating in this country, a British Steel Founders' Productivity team visited the United States early this year, and made a six-weeks' tour of steel foundries in that country. A report, giving the unanimous views of the team, was reviewed in our October issue in which we advised all engaged in the production of castings to give it very careful study because of the vital importance of the application of the conclusions formed by the team. So important were these conclusions regarded that the British Steel Founders' Association organised a productivity convention, to discuss the views expressed.

The convention was held at Ashorne Hill, Leamington Spa, on November 17th to 19th, inclusive, at which were representatives from almost every level of the steel foundry industry. Six sessions were held, dealing respectively with steel melting practice; feeding and gating; sand practice; mechanical aids; working conditions, incentives and method of payment; and administrative control. At each session a paper was presented, dealing particularly with American practice, and the subject submitted to general discussion, which was subsequently summed up by the chairman.

Acid electric melting is the more general practice in American steel foundries with twice the power input of equivalent arc furnace installations in Britain and the paper by Mr. A. C. Brearley on steel melting practice initiated a lively discussion on the application of high-speed melting operations in British foundries with particular reference to the acid electric arc process. Broadly, the discussion covered five main aspects: availability of scrap; power supply; process and layout; quality of product; and working conditions.

In his paper on feeding and gating, Mr. E. Daybell emphasised that much of the technique used in American steel foundries originated in this country and was taken by skilled craftsmen who emigrated to the United States. The paper proved to be of considerable interest, especially the ingenious applications of feeding heads and runner gates. After much discussion it was concluded that the steel foundry industry in this country had nothing to be ashamed of in view of the advance made in the last 20 years, but it was hoped that the productivity team's enthusiasm would remain infectious and the drive for efficiency be maintained by all.

The paper by Mr. J. Jackson and the subsequent discussion, at the third session, concentrated attention on the bearing of sand practice on productivity in the steel foundry. It was generally agreed that the fettling shop is the bottle-neck in the production of castings in this country and that improved sand practice would reduce the amount of fettling required. The opinion was expressed that green sand casting should be more widely used and that the greater use of the skin-drying technique would materially assist productivity.

The organisation of a number of American steel foundries was outlined by Mr. D. H. Aston, which did not differ to any great extent from normal arrangements in this country. The importance stressed was that some British steel founders must be reminded that without an efficient system of cost ascertainment they cannot know what their costs are, and that without a proper system of cost control they will go into battle to improve their productivity with only half a weapon.

Many suggestions with specific applications were brought out in group and general discussion. The larger aspects of the conclusions reached are embodied in the following resolutions unanimously adopted by those present at the final session:—

1. That steps be taken to secure adequate supplies of acid-melting scrap to the steel founders, to enable this economical melting method to be much more widely adopted.
2. That the B.S.F.A. should take action to obtain recognition of the priority power requirements of the steel-founding industry and amelioration of the inefficiencies of working which arise from load-shedding and staggered working hours when applied to steel-foundry power requirements.
3. That every endeavour be made to revise the present penalising power demand rates which retard the use of highly rated electric equipment.
4. That a team somewhat like the first productivity team, might, with advantage to the industry, tour steel foundries in Britain to report in like manner.
5. That periodic productivity conferences should be organised by the B.S.F.A. to encourage inter-change of experience and ideas relating to productivity, and to report progress.
6. That the Engineering and Allied Employers' Federation be asked to take urgent action to simplify the present wage structure and methods of calculating wages in the steel founding industry.
7. That co-operation among all those employed in the steel founding industry can only be achieved upon a basis of mutual respect, and that only in that spirit can the obstacles to high productivity be overcome.
8. That the convention accepts the principles and general recommendations in the productivity team report on steel founding and commends them to all who win their livelihood in the steel founding industry.
9. That the delegates representing all levels of workers in the steel founding industry, each and severally pledge ourselves, unreservedly, without fear or favour, to constant endeavour to increase the productivity of our industry.

ERRATA

On page 10 and top line of right column in our last issue "Mr. A. J. Brown" should read Mr. R. J. Brown.

Salt Baths for Annealing and Descaling

By Ernest Hague

Electric Resistance Furnace Co. Limited

The many advantages of the modern salt bath have been generally appreciated in recent years. The fact that work to be treated is sealed from contact with air immediately it is immersed is one of the main advantages; added to this, however, are rapid and uniform heating, accurate temperature, minimum distortion, etc., when used for heat treatment operations. Some of these advantages are also applicable when the baths are used for descaling. This article deals mainly with their application to annealing and descaling.

THE remarkable increase in popularity of the salt bath during recent years has been due to the growing appreciation of its many advantages, coupled with improvements in design and operating technique. It has also been found to be an excellent medium for many new heat treatment applications. In this article the application of salt baths for annealing and descaling operations is considered, but reference to the advantages usually associated with salt bath heating for many other purposes is of interest.

Advantages

Rapid and Uniform Heating.—Conduction heating in salt is much more rapid than radiation heating. Parts treated in salt baths attain the working temperature four to six times faster than similar parts treated in dry furnaces. In a properly designed salt bath the temperature is uniform throughout the whole of the salt space and, therefore, uniform heating of the work is guaranteed.

Freedom from Scale.—Molten salt protects metal surfaces by excluding air during immersion, and after removal of the metal from the bath the salt is present as a thin protecting film until the metal is quenched, or while it is cooled in air.

Accurate Temperature Control.—Parts attain the same temperature as the molten salt, so there is no need to make any allowance for temperature difference between the work and the thermocouple.

Minimum Distortion.—The salt bath lends itself readily to the suspension of articles, and, therefore, long slender parts can be treated with the minimum of distortion. Features of uniform heating and accurate temperature control also assist in the reduction of distortion.

Selectivity.—Parts may be partially immersed for selective heating.

Reduced Floor Space.—Because of the fast rate of heating a minimum size of plant is necessary.

Moderate Costs.—To obtain a similar product from an alternative plant usually involves a much greater initial cost and, in addition, the salt bath does not require the services of highly trained operators.

Annealing Carbon Steels

"Inter" or "Process" annealing is often carried out in salt baths after cold working, in order to make the metal suitable for further cold forming or for finishing operations. The charge, which may comprise coils of wire or rod, is heated to 650°/750° C. and removed

immediately, no soaking period being allowed. After cooling in still air the coil is washed and returned for further drawing.

A typical installation is shown in Fig. 1. It is rated at 225 kw., has internal dimensions 6 ft. long × 4 ft. wide × 4 ft. depth of salt, and is capable of heating one ton of coils of wire or rod to 700° C. every hour. The power consumption is of the order of 200/250 units per ton, and the total running costs, including power, salt and labour, amount to less than £2 per ton of material treated. The sum included for salt consumption is based upon a "drag-out" and salt volatilisation loss of 15 lb. per ton of coils processed.

The advantages of rapid and uniform heating, freedom from scale, accurate temperature control, etc., are all experienced with this salt bath. Moreover, freedom from decarburisation, a very important factor with the class of material treated in this bath, is achieved. Finally, maintenance costs have proved to be almost negligible.

Annealing Stainless Steels

The annealing of stainless steel is a particularly difficult problem owing to the high operating temperature required and, where cold rolled or cold drawn material is concerned, the desirability of maintaining the excellent surface finish or "bloom."

The conventional methods of treatment include batch furnaces for sheets, pressings, etc., continuous tube furnaces for wire and continuous furnaces of the "catenary" or "carrier strip" type for strip. With the catenary type equipment the strip is suspended between rollers located at the inlet and outlet ends of the furnace and the depth of the catenary controlled by special adjusting gear. In the case of the carrier strip design the material is supported on a continuous belt formed from a strip of stainless steel and which travels at the same speed as the work. Both the "catenary" and "Carrier" strip designs have been developed to prevent scratching of the material during treatment.

To obtain bright work a controlled atmosphere derived from a cracked ammonia plant is necessary, but this type of atmosphere, consisting largely of hydrogen, can only be applied with safety to the carrier strip and continuous tube-type furnaces where the working space is limited and in consequence easily purged and maintained free of air, eliminating the danger of explosion.

The salt bath may be regarded as a suitable alternative to any of the above furnaces, and a number of batch units are already in use for annealing stainless steel wire in coils and for annealing sheets and miscellaneous

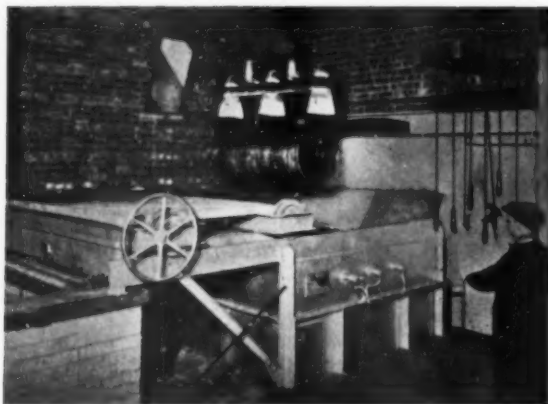


Fig. 1. An Efco-Ajax-Hultgren salt bath for the heat treatment of steel wire in coils.

pressings. Strip, too, may be effectively treated, continuously, in salt, using the catenary method of supporting the strip from rollers situated at the extreme ends of the bath. The heating time is extremely short, no more than two minutes being required for strip 0.14 in. thick, and 30 seconds only for very light gauges, resulting in a minimum length of bath for a given output. After passing over the exit roller the strip may be either air or water quenched as desired. The electrical consumption for a continuous strip annealing bath is approximately 300 units per ton.

If the material is of the cold-rolled variety its bright finish can be restored by a flash pickle in a warm 10% nitric solution, followed by a water wash, although it must be admitted that the "cold-rolled bloom," which the manufacturer is so anxious to retain, is lost.

The treatment of hot rolled strip in salt has definite possibilities. Experiments recently carried out indicate that the material, after treatment in the salt, can be fully descaled in a 10% nitric, 3½% hydrofluoric solution maintained at 65° C. in an average time of two minutes. The same material before annealing required eight minutes in the acid, suggesting that the annealing cycle itself has some action upon the scale.

A bath for annealing large stainless-steel pressings up to 6 ft. long \times 3 ft. 6 in. wide \times 2 ft. high overall has recently been installed. The unit, which is of the Efco-Ajax-Hultgren pattern, is rated at 225 kw., has internal dimensions 6 ft. 6 in. long \times 3 ft. 6 in. wide \times 5 ft. deep, and is designed to produce up to 10 cwt. of components per hour, at 1,150° C. The decision to install a salt bath was influenced by the necessity of obtaining a clean, scale-free pressing. In view of these conditions, the only alternative plant would have been a bell and base plant operating with a hydrogen atmosphere, which would have been more costly as regards both initial and running costs, and would necessitate great care in operation.

A second bath of similar design has been in operation for some considerable time, annealing stainless-steel rod

and wire in coils. This equipment is rated at 125 kw., and has working dimensions 3 ft. long \times 18 in. wide \times 3 ft. depth of salt. Two or three coils, having a total maximum weight of 150 lb., are annealed every 20 minutes at a temperature of 1,050°–1,150° C. A bath designed for annealing stainless-steel wire in coils is shown in Fig. 2. After quenching in cold water the material is passed through a drying oven and thence to a descaling bath, which is described later.

Annealing Nickel-Chromium Alloys

The heat treatment cycle for nickel-chromium alloys is very similar to that required for stainless steels, and, therefore, salt baths may quite well be used. The operating practice is to place the cold charge in the bath—maintained at 1,150° C., remove as soon as the temperature of the bath has recovered to 1,125° C., and

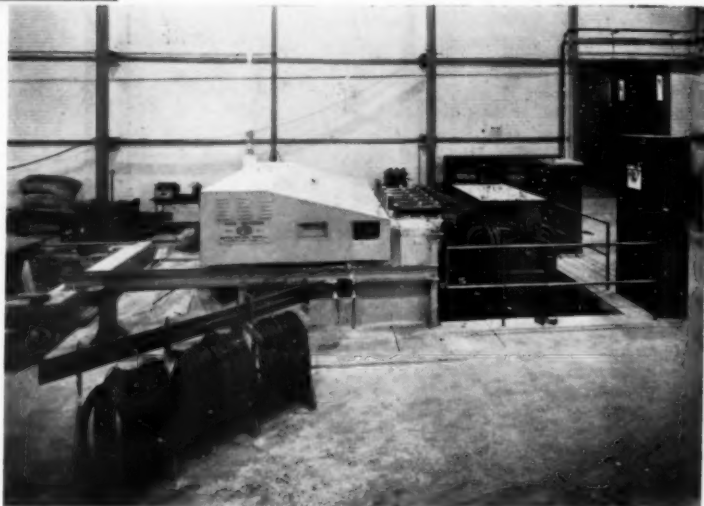


Fig. 2. A type similar to that shown in Fig. 1 but designed for annealing stainless steel wire in coils

quench in water. The bath is brought back to 1,150° C. before the next load is charged. This method of working produces the desired metallurgical structure with a minimum of surface attack. A salt bath rated at 150 kw., and having working dimensions 3 ft. 6 in. \times 1 ft. 8 in. \times 3 ft. 8 in. deep, has been installed to anneal 600-700 lb. of heat-resisting alloys coils of wire per hour.

Annealing Sterling Silver and Nickel Silver

These materials are normally annealed in a controlled-atmosphere furnace, but where slabs upwards of ½ in. thick are concerned it is sometimes desirable to use a salt bath, owing to the short heating time obtainable; for example: a ½ in. thick sterling silver slab can be heated to approximately 600° C. in 10 minutes, and a flash pickle only is necessary to clean up the surface.

Annealing Aluminium Alloys

Salt-bath annealing of aluminium alloy sheets, sections, etc., is firmly established, and many plants were installed during the recent war, using nitrate salts maintained at 400° C. This type of equipment was preferred by many light-alloy manufacturers, possibly because it provided a quicker form of heating and a greater uniformity of temperature.

There are so many installations for the treatment of aluminium alloys, varying in size up to 40 ft. long, and the process is so well known, that there is little point in detailing any specific application. However, Fig. 3 illustrates a unit for the solution heat treatment of large stampings. It will be noted that in this instance, a cage fixture is used to transfer the work from the salt bath to the water-quench, and finally to the water-rinse tank.

Cyclic Annealing

This process involves the use of the so-called "S" or time-temperature-transformation curves, which have been prepared for various steels because of the development of isothermal heat treatment. It necessitates the use of two salt baths, the work being heated to its austenitising temperature in one, and quenched in the other. The quench-bath is controlled at a temperature within the pearlitic range as shown by the "S" curve for that particular steel, and the work remains in the salt until the transformation is completed, after which it is removed and cooled at any rate desired. This cyclic annealing process offers better control than is normally obtained by extremely long, slow cooling, and is strongly advocated wherever the saving of time is an important factor.

Descaling

Recent developments in connection with this subject include the introduction of the Virgo and sodium-hydride processes of molten salt descaling. The main features of the processes are rapidity of action, no loss of base metal—the scale only being attacked—excellent surface finish and freedom from hydrogen embrittlement. These features are of particular importance where expensive alloys, such as stainless, heat-resisting and high-speed steels are concerned.



Fig. 4. A plant using the Efco-Virgo process for descaling bars



Fig. 3. Showing the salt bath applied to the solution treatment of aluminium alloy stampings

Efco-Virgo Descaling.—For this process a salt of patented composition is used, maintained at 480–540° C. and consisting of caustic soda with various activating agents which chemically convert the oxide to one of flocculent nature and capable of solution in a weak acid. In addition there is a physical action due to the volume increase of the scale which accompanies the chemical conversion, with the result that the rupturing effect of the steam produced in the cold water quench is sufficient to dislodge the greater part of the scale, leaving the remainder as a loosely adherent fine deposit.

Although in some instances this finish is satisfactory, it is the general practice to follow the water quench with a flash pickle in warm, diluted acid and a final water wash, in order to produce a bright surface. The time of immersion in the salt bath varies from 2 to 20 minutes, depending on the degree of scale, weight and thickness of charge, etc., and the duration of the acid dip is of the order of 1 minute only.

A unique feature of the salt is that it is self-regenerative, the activating agents in the salt, which convert the scale being reconverted to their original composition by the action of atmospheric air. Because of this feature it is only necessary to add new salt equivalent to the amount lost by drag-out, in order to maintain the salt in perfect condition. The actual salt consumption is dependent upon the application, but for batch work an average of 10 lb. per ton of work may be assumed.

Reference was made earlier to a Virgo descaling bath, working in conjunction with an annealing bath, handling stainless-steel coils of rod and wire. This descaling bath is rated at 35 kw., and has internal dimensions 3 ft. 9 in. long × 2 ft. wide × 3 ft. 6 in. depth of salt.

The annealed material, after drying, is placed in the descaling bath for a period of 10 minutes, quenched into cold water and then flash pickled in diluted acids of hydrochloric and nitric in turn, both

acids being maintained at approximately 60° C. The process is completed with a water-wash and spray, leaving the material descaled and with an excellent surface finish.

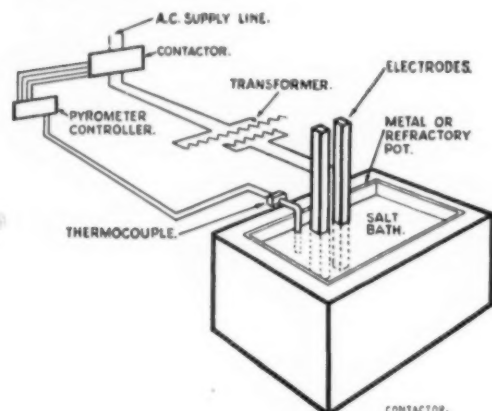


Fig. 5. A schematic arrangement of a salt bath with one pair of electrodes

Sodium-Hydride Descaling.—This process employs molten caustic soda operating at a temperature of 350°–370° C., and containing a reducing agent of approximately 2% of sodium hydride. The action is such that the scale present on the work is reduced to loosely-adherent metal which may be quickly and easily removed. As with the process previously mentioned, most of the converted scale is removed by the blasting action of the steam generated as a result of quenching into cold water, and a subsequent flash pickle is necessary to ensure a bright finish. Here again the time of immersion in the salt bath may vary from 2–20 minutes, and in the acid dip, approximately 1 minute.

The sodium hydride is generated in the caustic soda by a direct reaction between metallic sodium and hydrogen, the latter being added continuously, and the former at intervals of approximately one hour. Special generator boxes, of which there may be one or more, depending on the size of bath, are provided into which the sodium and hydrogen are fed and mixed.

A generator consists of a mild-steel box, open at the bottom and partly immersed in the caustic soda. The sodium is fed through a charging hole in the top of the box and hydrogen is passed through a pipe, the end of which is below the salt level. The sodium melts and forms a fluid layer floating on top of the caustic soda, and the hydrogen bubbles up to meet it. The sodium hydride thus formed disperses evenly throughout the bath without the need of any special stirring device.

The hydrogen is usually obtained from dissociated ammonia with the aid of an ammonia-cracker. The resultant mixture is 75% hydrogen and 25% nitrogen, but the latter is inert and takes no part in the reaction.

Two such Efco-Ajax-Hultgren electrode salt baths were installed some time ago in the Sheffield area. One unit is engaged on descaling coils of stainless-steel rod and wire, and the other primarily, for descaling high-speed

steel rod in coils. The baths are identical, being each rated at 100 kw., and having working dimensions 6 ft. × 3 ft. 6 in. × 3 ft. 6 in. depth of salt. The output from each plant is of the order of 1 ton of coils per hour with a power consumption of 90 units per ton. The consumption of sodium and ammonia amount to 15–20 lb. and 6 lb. per ton, respectively. Caustic soda consumption is negligible, the amount of “drag-out” being offset by the formation of new caustic soda, as a result of the additions of sodium and hydrogen.

Both processes were first introduced for batch descaling, but continuous units are now in operation for strip, wire and sheets. In the ferrous field the processes show their greatest advantage with the expensive alloy steels where the metal wastage in pickling is a serious debit item, and particularly in the stainless grades where, in addition, acid pickling is difficult and costly. With plain carbon steels which are, in general, easily handled in acid pickling plants, the advantages are less pro-

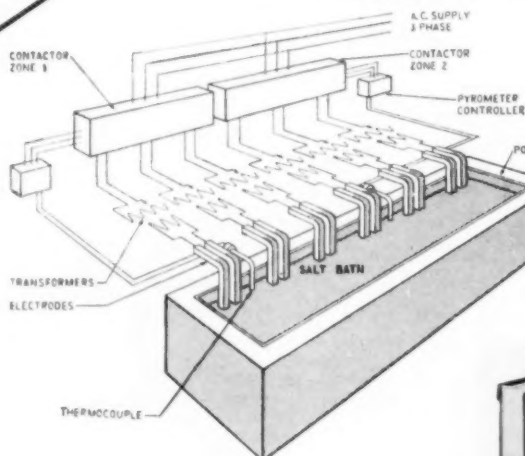


Fig. 6. A multi-electrode arrangement for a large batch-type salt bath

nounced; nevertheless, plants are in operation, producing a superior finish with competitive running costs.

In the non-ferrous field, copper alloys, etc., or, in fact, any alloy that is not attacked by caustic soda, or whose properties are not impaired by heating to the requisite working temperature, can be descaled by these methods. A plant utilising the Efco-Virgo process for descaling bars, etc., is shown on Fig. 4.

Equipment for Annealing and Descaling

Electrode salt baths may be used for all the treatments described,



Fig. 7. The arrangement for deep salt baths is by a cascade of electrodes as shown

and are, in fact, essential for such purposes as annealing stainless steels, nickel-chromium alloys, etc. For low-temperature treatments, such as annealing aluminium alloys, molten salt descaling, etc., gas-fired baths or electric immersion heater baths, may be employed.

The Efco-Ajax-Hultgren electrode salt bath is a particularly suitable design, as it possesses many advantages, and may be worked at temperatures up to 1,300–1,400° C. It employs pairs of electrodes (sometimes one pair only in the case of a small bath), immersed in the salt and positioned in close proximity to one side of the salt container. Each pair of electrodes is connected to a low-voltage (approximately 10 volts) single phase supply, and arranged so that there is a gap between the two electrodes of 1–1½ in. The salt when molten is a conductor and is, therefore, heated by virtue of its own resistance to the flow of current. The patented arrangement of the electrodes creates electrodynamic forces which cause the salt to circulate, with the result that a uniform temperature distribution is obtained throughout the whole of the bath. The arrangement of this salt bath, with one pair of electrodes, is shown schematically in Fig 5, while that shown in Fig. 6 is the design of a larger unit; having a number of pairs of electrodes.

In addition to promoting a circulating action in the salt the unique, closely spaced arrangement of the electrodes has further advantages. One of these is of immense importance inasmuch that it is standard practice when shutting down to allow the salt to solidify and then, when required, restart from the solid state. Thus "baling out" may be eliminated with the consequent saving in time, salt, and in some instances, power. To restart it is only necessary to melt the small quantity of salt between the electrodes to a depth of 3–4 in. in order to establish a circuit between them. This may be done by passing current through granulated carbon placed in the electrode gap, or alternatively, a gas torch may be used, operating with a comparatively soft flame.

The salt container in this design of bath may be of either metallic or refractory construction, the former being used for low-temperature treatments, such as annealing aluminium alloys, descaling, etc., and for any treatment requiring a salt containing cyanide. For annealing stainless steels, nickel-chromium alloys, etc., or, in fact, for any medium or high-temperature treatment requiring the use of a neutral salt, a refractory container should always be used. If these recommendations, which are based upon actual experience, are followed the maximum life of the pot will be obtained. A "neutral" salt is one that is neither carburising or decarburising in action. It does not contain cyanide.

The electrodes usually comprise 2 in.-square straight mild-steel bars, which are connected through step-down transformers to the main low-tension supply. When used with a refractory lining the electrodes are generally knee-shaped, with the horizontal portion built into the side wall of the bath. In operation, the horizontal portion of the electrode is submerged in the molten salt, but when solidified the salt shrinks and exposes the upper part of the electrodes, allowing the standard method of re-starting to be effected. The advantage of this design is that a longer life of electrode is achieved; failure with earlier designs usually being associated with attack at the salt line.

This new development has also enabled very deep salt baths to be built, a number of electrodes being arranged down the side of the bath, as shown on Fig. 7. Hitherto, of course, it has not been practicable to make a deep electrode bath because of the mechanical difficulty of providing a long electrode. Restarting from solid, a deep bath, with a cascade of electrodes, is a comparatively simple matter, the required pool of salt being melted between the top pairs of electrodes, after which the salt gradually melts downwards until the lower electrodes are reached, when automatically they begin to pass the current.

Conclusions

The foregoing will serve to emphasise the important advantages associated with salt-bath heating, and to indicate the present scope of the treatment with respect to annealing and descaling. The numerous installations already in use suggest the possibility of even wider applications in the future.

The 750 ft. Television Mast at Sutton Coldfield

THE newly completed television mast at Sutton Coldfield, Birmingham, has brought the television service within the range of about 6 million more potential viewers. The mast, which exemplifies the degree of collaboration between the electrical and civil engineer—an essential in all projects of this type—was designed, supplied and erected by British Insulated Callender's Construction Co. It is an impressive steel structure over twice the height of St. Paul's and is the tallest television mast in the world. The first 600 ft. is of lattice work construction with a 9-ft. triangular cross section, but the next 110 ft. is tubular and constitutes a special purpose v.h.p. sound broadcasting aerial. Surmounting this is a short square tower, carrying a new and improved television aerial system which has a broadcasting range of about 50 miles. This is a cautious estimate and an even greater range can be expected.

The mast, which has an overall weight of some 140 tons, is pivoted at its base over a small steel ball of 2 in. diameter. The pivot, of which this ball forms the central point, is called upon to withstand a maximum thrust of 350 tons, and under the most severe weather conditions allows for a movement of 7 ft. 6 in. from the perpendicular at the mast head. Within its narrow framework, 9 ft. across each face, a two-man lift takes engineers up to the 600 ft. level, contact being kept with the ground by use of walkie-talkie equipment designed by British Telecommunications Research, Ltd., an associate company within the BICC Group.



View of the complete mast from the south-west.

Electroplated Tin-Zinc Alloy Coatings on Iron and Steel Components

By E. E. Halls

Developed by the Tin Research Institute, the tin-zinc electrodeposited coating for the protection of iron and steel is discussed in this article. For resistance to damp conditions and ease of soldering it is better than zinc, whilst for spot welding it is superior to cadmium. Details are given of the plating process together with the results of comparative corrosion tests.

DURING the last twenty years, notable advances have been made in applied finishing for the protection of iron and steel work, and probably in no previous similar period has the practical finishing technician applied to advantage so much from the laboratory and research organisation. The war period accounted for some of this advance because so many early failures had to be investigated and corrected; results from service performance were often available quickly to give correlation between theory and practice; many new finishing plants had to be started with technical control from the outset; and, in general, sound information was "pooled" so that much of the mystery and consequent secrecy of finishing disappeared.

In the field of electroplating, the significance of thickness of coating, so long appreciated by technicians, has been generally accepted by electroplaters, and the still more important feature of "minimum local thickness" is being given more consideration. The impossibility of operating electrolytes without periodic analytical checks to maintain the optimum concentration and balance of ingredients is more widely granted by practical platers. These are some of the more obscure aspects of finishing, the observance of which has resulted in improved products and wider application. From the truly research side, electroplated tin/zinc alloy coatings may be cited as a real advance in the protective finishing of iron and steel components. The Tin Research Institute is responsible for the prolonged laboratory and applied researches which culminated in a practical process for the deposition of this coating. The research was complete in the sense that full details have been made available for the installation and maintenance of the process.

Cadmium and zinc are the normally recognised electroplate coatings for the protection of iron and steel. They provide sacrificial protection in the sense that they are electropositive to iron and, under adverse circumstances, they provide protection by themselves corroding. Naturally, they each have their shortcomings as well as advantages and each has passed through periods of condemnation, generally resulting from faulty application rather than inherent defects.

Comparative Merits

With cadmium, premature failures have been experienced due to flaking, rapid whitening and early rusting. These have been traced to mere flash coatings or deposits of inadequate thickness; to strained coatings due to excessively high-current densities; and to faulty process control causing erratic, non-uniform coatings. With a proper appreciation of these features, cadmium plating has emerged to be recognised as a sound protective

finish for iron and steel, and in some industries it has been standardised as the preferred electroplate coating for this purpose. It has better resistance to humid conditions, particularly to high humidities and condensation, than has zinc plating, and it exhibits good resistance to marine conditions. It is favoured by the radio industry, not only for these reasons, but also for its good appearance, retention of this appearance, and on account of the ease with which soldered contacts can be made to it using non-corrosive resin fluxes. Its resistance to deterioration can be further enhanced by the simple process of chromate passivation.

With zinc plating, early serious failures were all due to inadequate thickness of coating. Poor results may also result from the use of the easily maintained sulphate electrolyte which has a deplorably poor "throwing power," and which, therefore, provides very little protection on the insides of bends and in recesses. The cyanide electrolyte overcomes this defect, although its throwing power is not quite so good as that of the cadmium electrolyte. This solution is more difficult to maintain, but no trouble arises if laboratory control is exercised. Uniformity of appearance is not so good as with cadmium, nor is resistance to humidity. Rapid whitening occurs under conditions of condensation and soldering is not practicable using resin flux. Generally speaking, zinc-plate coatings need additional protection to offset this deterioration under damp conditions—i.e., in most cases it is essential for zinc but not so for cadmium. Chromate passivation gives this preservation in a very simple and economic manner, but the resulting appearance is not always acceptable on account of variegated colour. Lacquering with a thin film of nitro-cellulose lacquer is a usual procedure for safeguarding this shortcoming. The soldering problem can be solved by the provision of "tinned tags"—i.e., tags formed by punching the component or by spot-welding separate tags which are hot tinned or soldered prior to plating, or by mere mechanical contacting.

Two other facts concerning cadmium must not be overlooked. The first is cost, which, during the last few years, has been very high indeed. The other is availability; total cadmium production is small and probably could not supply all the needs that are satisfied by zinc. Furthermore, in recent years periods have been encountered, and are likely to be re-encountered, when cadmium has not been available for finishing purposes.

The tin/zinc alloy platings are relatively new to industry, and in consequence results from years of experience with them, as with zinc and cadmium platings, cannot be cited. Premature failures, however, are not anticipated because the need for process control,

and for adequate and uniform thicknesses, are appreciated by all who adopt the process. The coatings exhibit very good resistance to salt conditions; and quite a good performance under damp exposure, the latter quality being further improved by a simple chromic acid passivation treatment. The coatings are solderable. Over the surfaces of irregular shaped articles, some variation in the ratio of tin to zinc in the coating must be expected, however closely the process is maintained.

Plating Process

With the tin/zinc alloy platings, alloys of a range of composition can be deposited, the two generally exploited being 50/50 and 80/20 tin-zinc. Anodes of the respective composition are employed, and electrolytes of the appropriate composition have to be used; full details are provided by the Tin Research Institute and the following processing data are taken from their publications. The recommended conditions are as follows:—

	80/20 alloy	50/50 alloy
Tin content of electrolyte ..	30 gm./litre	30 gm./litre
Zinc ..	2.5 "	8 "
Free sodium hydroxide ..	4-6 "	6-8 "
Sodium cyanide ..	25 "	50 "
Cathode current density ..	15/30 amp./sq. ft.	15/30 amp./sq. ft.
Temperature ..	70° C.	70° C.

It will be noted that the electrolyte is, in effect, a combination of the sodium-stannate tin and zinc cyanide solutions. It is strongly alkaline, and therefore the containing tank can conveniently be iron. As in stannate tin plating, the tin in the electrolyte must be maintained in the stannate condition and the anodes in the filmed condition. The filming follows the same practice as in tin deposition—i.e., it is achieved by slowly lowering them into the solution with the current on, or by inserting all the anodes and polarising for a few seconds at high voltage. Once filmed, the anodes can safely be left in the solution without current flowing for an hour or two, but if the installation is out of use for longer periods, they should be removed.

Proper control ensures uniform operation of the process. The Tin Research Institute state that the composition of the plate deposited is a linear function of the caustic soda content of the electrolyte, and analysis for this ingredient provides the main simple control. Cyanide becomes hydrolysed and reduces relatively rapidly, as would be expected in a solution operating at a high temperature, and this may necessitate daily additions in large vats. Tin and zinc should not vary greatly and only require infrequent periodic checking. Carbonate gradually increases due to decomposition of the cyanide and absorption of carbon dioxide from the atmosphere, and this operates in the direction of reduced cathode efficiency. This is not very serious, however, and in excessively carbonated solutions, the loss does not exceed 20%. Periodically, carbonate may require removing, cooling and crystallising being the method employed. Traces of nickel markedly reduce the cathode efficiency, so that contamination by this element must be carefully avoided.

After plating, work is thoroughly washed in cold and hot waters, and may then be dried or passivated. The latter comprises a few seconds immersion in a 2% solution of chromic acid. Fifteen seconds at 50° C. or 5 seconds at 80° C. give a guide to the temperature/time relationship for this immersion. Cold and hot water rinsing, and drying follows. The passivation

treatment does not affect the grey-white colour of the finish unless the immersion times are extended, in which case, a yellow or brownish coloration results which is not detrimental except from the colour point of view. The passivation helps to minimise finger-mark staining, and does add to the protective value of the coating insofar as it adds to its humidity resisting properties.

Tin/zinc plating can follow the usual sound cleaning and preparatory treatments. Iron and steel are the usual metals to which the process is applied, but there is no reason why it should not be applied to the non-ferrous metals. When used on soldered components, the normal practice of a preliminary deposition of copper from a cyanide or Rochelle salt solution may be adopted; alternatively very thorough cleaning of the solder areas is necessary, using a wire brush and pumice, otherwise blistering at these points is liable to occur.

Tin itself is not normally employed as a protective electroplate coating on iron and steel because it is electro-negative to iron. When it is used on steel components for specific reasons, a minimum average thickness of coating of 0.001 in. is desirable (reference D.T.D. Spec. 924). Under comparable circumstances, minimum average thicknesses of 0.0005 in., or minimum local thicknesses of 0.0003 in., for both zinc and cadmium are stipulated (reference D.T.D. Specs. 903 and 904, respectively). For normal service conditions, 0.0005 in. minimum average thickness of tin/zinc, or 0.0003 in. if passivated, is usually recommended, with greater thicknesses for more severe conditions. The tin/zinc alloy would be expected to resist damp conditions without white corrosion better than zinc itself, and without pin-hole rusting better than tin. Its soldering properties should be akin to those of tin itself, with better solderability the higher the tin content. This anticipated performance is achieved in practice.

It will be appreciated that in plating components, the uniformity, or lack of uniformity, of the deposit over the surface of each article, is primarily dependent upon the "throwing power" of the electrolyte, and secondarily upon control of conditions to achieve the best possible throw. In alloy plating, equal throw of the constituent metals cannot be anticipated. With tin/zinc, the tin exhibits better throwing power than the zinc, so that on prominences the zinc content of the deposited alloy may be rather higher than the average, while in remote areas and in recesses it will be lower. At the bottom of very deep recesses, almost pure tin may be deposited. Disposition of anodes can be adjusted to some degree to minimise the discrepancy. At the same time it is important to note that the throw of tin/zinc is markedly superior to that of zinc alone, even when the latter is plated from cyanide electrolytes. In fact, inside sharp corners and bends of components that do not become covered in zinc plating, become plated from tin/zinc alloy electrolytes.

Durability Tests

In the following, typical durability test results are presented for irregular steel components plated with tin/zinc finish, with comparative average data for zinc and for cadmium coatings. Table I gives thickness values for the tin/zinc alloy plating on samples of the specimens subjected to tests. The position at which the thickness was determined is indicated, the actual estimation being made by cutting a specimen approximately 1 in. square, stripping the finish from it in cold

TABLE I.—AVERAGE OR LOCAL THICKNESSES OF TIN-ZINC ALLOY COATING ON TEST SPECIMENS

Sample No.	Nominal Average Composition of Coating %	Nature of Test Pieces	Position of Thickness Test	Total Thickness of Coating Inches $\times 1,000$	Actual Composition of Coating	
					Tin %	Zinc %
1	80 Tin, 20 Zinc	Flat panel.	$\frac{1}{8}$ in. from corner.	1.10	74.0	26.0
2	ditto.	Large formed and perforated component.	Centre of panel.	0.73	75.6	24.4
3	ditto.	Small angular pressing.	Centre of side flange.	0.87	73.5	26.5
4	50 Tin, 50 Zinc	Large formed and perforated component.	Centre of main surface.	0.68	76.1	23.9
5	ditto.	Small angular pressing.	Average.	1.30	72.8	27.2
			Centre of side flange.	0.61	66.2	33.8
			Centre of main surface.	0.47	71.9	28.1
			Average.	1.12	49.5	50.5

TABLE II.—PERFORMANCE OF TIN-ZINC ALLOY-PLATED MILD-STEEL COMPONENTS UNDER SALT-SPRAY TEST

Sample No.	Type of Tin-Zinc Alloy	Period of Salt-spray Test in Days		
		1	7	21
1	80/20	Surfaces generally darkened together with slight white corrosion patches, heavier near edges.	White corrosion heavier, otherwise no change.	White corrosion still heavier, otherwise no change. No rusting.
2	80/20	General darkening of appearance and very slight white patches giving an overall mottled appearance. Areas at inside angular corners unaffected.	ditto.	ditto. Inside corners still not affected.
3	80/20	Dark background with slight white corrosion patches, giving mottled affect, but with inside corners unchanged.	ditto.	ditto.
4	50/50	White corrosion rather heavier than in sample No. 2, otherwise similar deterioration.	ditto.	ditto.
5	50/50	White corrosion heavier than in sample No. 3, but deterioration similar in other respects.	ditto.	ditto.

TABLE III.—PERFORMANCE OF TIN-ZINC ALLOY PLATED MILD STEEL COMPONENTS UNDER TROPICAL TESTING TO W.T. BOARD SPEC. K.110.

Sample No.	Type of Tin-Zinc Alloy	Performance under the following cycles				
		1 dry	4 wet	8 wet	12 wet	21 wet
1	80/20	Unaffected.	Darkened to dirty appearance.	Very slight whitening on dark background.	Further whitening and a few tiny rust spots developed on centre of plate.	White corrosion not very intense although appearance dirty and unattractive. Rust spots numerous but not large.
2	ditto.	ditto.	ditto.	Slight whitening on dark background, a few rust spots developed.	Further whitening and a few more tiny rust spots formed.	White corrosion not heavy, many general rust spots, but also patches of them on unwhitened areas adjacent to inside corners.
3	ditto.	ditto.	ditto.	Slight whitening on dark background.	Further whitening, but no rusting.	Slight further whitening, dirty appearance, but only a few rust spots.
4	50/50	ditto.	Darkened generally with some white corrosion areas. Rust spots on areas at inside bends, which were otherwise unaffected.	Rust spots developing generally on inside surfaces.	Inside surfaces heavily spotted with rust.	White corrosion on outside surfaces on a darkened background, but no rust, heavy rust on inside surfaces, especially adjacent to angular bends.
5	ditto.	ditto.	Darkened to a dirty appearance.	General white corrosion beginning to develop.	Further whitening.	General fairly heavy whitening but no rusting.

concentrated hydrochloric acid, and analysing the solution obtained for tin and zinc. The values indicate very good throwing power of the tin/zinc alloy as a whole, and the rather greater throw of the tin. The latter is shown by the values for percentage tin in the coating being a little higher in the centre of main surfaces than near corners or on side flanges.

Table II deals with these components under a vigorous salt-spray test. The conditions comprised exposure at room temperature to the mist produced by atomising 20% salt solution with clean, moist compressed air. The specimens were obliquely arranged in the test cabinet and protected by glass baffles from the impingement of large droplets. The atomiser was operated during the eight-hour day period, and the specimens left in the mist-laden chamber overnight. Before re-starting the atomiser, the samples were removed, rinsed in cold running mains water and dried on a soft cloth for

examination. The details of performance during the test, show the value of the coating in giving protection against salt atmospheres, the lack of rusting at the end of 21 days being regarded as very good indeed. It will be noted that the heaviest white corrosion products formed at areas where the zinc concentration in the deposit would be highest, and that no such deterioration occurred in inner corners where the tin predominated.

Table III details performance under cyclic tropical testing to Wireless Telegraphy Board Specification K.110. The cycles were of 24 hours' duration, the dry one being 6 hours dry heat at 71° C., and the wet one 6 hours at 60° C. followed by cooling off with condensation upon the specimens in the moisture-laden cabinet for the remainder of the 24-hour period. It will be seen that under these conditions, the coating fulfils its role of protecting by itself deteriorating, no very serious degradation of the base metal occurring. The dry heat,

TABLE IV.—PERFORMANCE OF ZINC-PLATED MILD-STEEL COMPONENTS UNDER SALT-SPRAY TEST

Sample No.	Nature of Test Pieces	Thickness of Zinc Coating, Ins. \times 1000		Period of Salt-spray Test in days		
		Minimum Local	Average	1	14	28
1	Flat panels.	0.3	0.5	Mottled appearance, dirty grey in colour.	General whitening, heavy white corrosion at edges.	Heavy whitening general, and a number of tiny rust spots generally distributed.
2	Miscellaneous angular pressed components.	0.3	0.62	Mottled appearance and white corrosion.	Outer surfaces showing signs of rusting, inner surfaces fairly heavily rusted (first signs in 7 days).	General rusting.
3	ditto.	0.6	1.2	Mottled appearance and white corrosion.	Heavy white corrosion, traces of rust on inner surfaces.	Fairly general rusting on inner surfaces, none on outside surfaces.
4	Large formed components.	0.6	1.0	ditto.	Heavy white corrosion.	Heavy white corrosion, but only minute traces of rusting on inside bends.

TABLE V.—PERFORMANCE OF ZINC-PLATED MILD-STEEL COMPONENTS UNDER TROPICAL TESTING TO W.T. BOARD SPEC. K.110

Sample No.	Nature of Component	Thickness of Zinc Coating, Ins. \times 1000		Performance under the following cycles:—				
		Minimum Local	Average	1 dry	4 wet	8 wet	12 wet	21 wet
1	Machined and pressed small components.	0.2	0.35	Unaffected.	Heavy white corrosion.	White corrosion heavier.	White corrosion heavier.	Very heavy white corrosion, few only rust spots.
2	Flat panels.	0.3	0.5	ditto.	ditto.	ditto.	ditto.	Heavy white corrosion, and a few tiny rust spots in centre of panels.
3	Large formed component.	0.3	0.5	ditto.	ditto.	A little rust inside bends.	Whitening more marked.	Very heavy white corrosion and appreciable rust inside bends, and on inside surfaces.

TABLE VI.—PERFORMANCE OF CADMIUM-PLATED MILD-STEEL COMPONENTS UNDER SALT-SPRAY TEST

Sample No.	Nature of Test Pieces	Thickness of Cadmium Coating, Ins. \times 1000		Period of Salt-spray Test in Days		
		Minimum Local	Average	1	14	28
1	Flat panels.	0.4	0.62	Slight general white corrosion.	Fairly heavy general white corrosion against a dark-coloured background.	White corrosion very heavy, a few tiny rust spots.
2	Miscellaneous small angular machined components and pressings.	0.15	0.25	Darkening in colour and slight white corrosion.	Rust started in 7 days, fairly heavy in bends and on inside surfaces.	General rusting rather heavy.
3	ditto.	0.3	0.5	Slight general whitening.	White corrosion against a black background.	Some rusting, but not very general.
4	ditto.	0.6	1.0	ditto.	ditto.	Little further deterioration; no rusting.

as would be expected, is without effect, and the first four wet cycles cause slow attack on the coating. This results in the pleasing whitish grey appearance darkening and, by contrast, looking dirtyish; rust appeared on the inner bends of one sample only—i.e., the sample having the thinnest coating. At the end of the 21 wet cycles, it should be noted that of the two similar specimens, Nos. 3 and 5, No. 3 with higher tin content showed rust spots and No. 5 with lower tin was free from rust. In comparison, the 80% tin samples Nos. 1 and 2 had thinner coatings, and showed more rusting, whilst the 50% tin sample No. 4 had a much thinner coating and showed appreciable rusting. The rusting in all cases was associated mainly with the lower zinc areas of the coating—i.e., areas adjacent to inside bends and corners.

For comparison, typical durability test results are given for components zinc plated from cyanide electrolytes, salt-spray performance in Table IV, and K.110 tropical testing in Table V. Under the salt-spray, performance is very good, but the extent of corrosion

of the coating is heavier, and the appearance of rusting earlier than with the tin/zinc specimens. In the case of the tropical wet tests, the volume of white corrosion was heavier, but the appearance of the rusting not so early in the test cycles as with the tin/zinc specimens.

Cadmium coatings are dealt with in Tables VI and VII. The salt-spray results are similar to those for the zinc coatings, only the very thin cadmium coatings (sample No. 2) showing marked rusting. Under the cyclic wet tests, rusting commenced at periods commensurate with the thickness of coating, all of which were relatively thin. Taking the latter into consideration, the cadmium coatings were equal or superior to the tin/zinc platings under damp conditions, and superior with respect to the development of white corrosion compounds, although inferior for rust proofing, to the zinc coatings.

In Tables VIII and IX, zinc and cadmium coatings similar to those dealt with above but chromate passivated to D.T.D. Spec. 923 are considered under the

TABLE VII.—PERFORMANCE OF CADMIUM-PLATED MILD-STEEL COMPONENTS UNDER TROPICAL TESTING TO W.T. BOARD SPEC. K.110

Sample No.	Nature of Component	Thickness of Cadmium Coating Ins. \times 1000		Performance under the following cycles :—				
		Minimum Local	Average	1 dry	4 wet	8 wet	12 wet	21 wet
1	Machined and pressed small components.	0.20	0.30	Unaffected.	Colour dark and considerable rusting.	Little further change.	Rusting more marked.	Colour very dark, rust on most surfaces and especially on edges.
2	Large formed component.	0.20	0.30	ditto.	Colour considerably darkened.	Some rusting in corners and bends, and on edges.	Little change.	Little change, rusting more intense, but not more extensive.
3	ditto.	0.10	0.15	ditto.	ditto, also rust appearing in bends.	Rust deeper.	Rust more intense.	Very dark and much rust in bends, edges and on inside surfaces.
4	ditto.	0.15	0.25	ditto.	Darkened and rust appearing inside bends.	ditto.	ditto.	ditto.

TABLE VIII.—PERFORMANCE OF MILD-STEEL COMPONENTS, ELECTROPLATED AND CHROMATE PASSIVATED (D.T.D. 923) UNDER SALT-SPRAY TEST

Sample No.	Nature of Plating	Thickness of Metal Coating Ins. \times 1000		Nature of Component	Period of Salt-spray Test in Days		
		Minimum Local	Average		1	14	28
1.. ..	Zinc.	0.3	0.5	Flat panel.	Unaffected.	A few black spots.	General whitening, but very slight and most intense at edges.
2.. ..	Zinc.	0.3	0.5	Large formed component.	Unaffected.	ditto.	ditto.
3.. ..	Cadmium.	0.4	0.62	Flat panels.	Unaffected.	Unaffected.	Slight darkening in a number of areas, no corrosion and condition very good.
4.. ..	Cadmium.	0.20	0.30	Formed components.	Unaffected.	Unaffected.	ditto.

salt-spray and tropical wet conditions. Their performance under these tests is exceedingly good.

For the zinc and cadmium platings, the following process conditions were employed :—

ZINC

<i>Electrolyte :</i>	
Single Zinc Cyanide	10.9 oz.
Sodium Cyanide	4.5 oz.
Sodium Hydroxide	8.8 oz.
Aluminium Sulphate	1.0 oz.
Water to make	1 gal.
Temperature	25°-30° C.
Cathode Current Density	10-20 amp./sq. ft.

CADMIUM

<i>Electrolyte :</i>	
Cadmium Oxide	54 oz.
Sodium Cyanide	12 oz.
Dextrin	4 oz.
Water to make	1 gal.
Temperature	Room (15°-25° C.)
Cathode Current Density	10-15 amp./sq. ft.

The chromate passivation was applied to the zinc and cadmium-plated parts while still wet from the washing after plating, and consisted of immersion for 5-10 seconds at room temperature in the following solution :—

Sodium Dichromate Crystals	2 lb.
Sulphuric Acid	1 fluid oz.
Water to make	1 gal.

The passivated work was thoroughly washed in cold water, and then dried off from warm water at a temperature not exceeding 60° C.

Soldering and Resistance Welding

The finishes discussed are of particular interest to the light electrical industries. The standard electroplate coating for the protection of iron and steel in the telecommunications industry is zinc, while the radio industry

generally prefers cadmium. The reasons for this last choice are, first, good resistance to damp conditions without lacquering or enamelling; second, ease of soldering. Electrical connections using soft solder must be made with a non-corrosive resin flux. Chloride fluxes, which cannot be washed off finished components or assembled apparatus, are prohibited because of the corrosion promoted by them. Under these conditions, zinc or passivated zinc cannot be soldered. Cadmium plate is easily solderable; passivated cadmium is only a little more difficult than cadmium itself. The tin/zinc alloy platings are readily solderable, and the chromic-acid filming does not impair this facility. The only other comment to be made on the solderability of tin/zinc alloy is to the effect that if in bit-soldering, the iron is rubbed to and fro several times in making the junction, the zinc constituent causes a scum to rise on the solder, affecting the neatness of the junction, rather than its efficiency.

The remarks made on the solderability of these plated coatings apply also to the coatings after submission to 6 or 8 wet cycles of the K.110 tropical test, indicating that plated components can be stored for very considerable periods and still retain their soldering qualities.

Another important feature, especially for radio and many other types of electrical components, is suitability for resistance welding. Chassis, frames, bases, etc., may be fabricated by spot-welding, and the component parts are electroplated before the joining operation, otherwise electrolyte is retained in the overlapping junctions. The welding of coated steel is more difficult than plain mild steel. Higher power must be available, closer control is

TABLE IX.—PERFORMANCE OF MILD STEEL COMPONENTS, ELECTROPLATED AND CHROMATE PASSIVATED (D.T.D. 923) UNDER TROPICAL TESTING TO WT. BOARD SPEC. K.110

Sample No.	Nature of Plating	Thickness of Metal Coating Ins. $\times 1000$		Nature of Component	Performance under the following cycles :—				
		Minimum Local	Average		1 dry	4 wet	8 wet	12 wet	21 wet
1 . . .	Zinc.	0.30	0.60	Miscellaneous small machined components.	Unaffected.	Very slight whitening at edges.	Slight increase in whitening.	Slight increase in whitening.	Exceedingly light white corrosion film on 50% of surfaces, no rusting, condition very good.
2 . . .	Zinc.	0.40	0.80	Large formed components.	ditto.	ditto.	ditto.	ditto.	ditto.
3 . . .	Cadmium.	0.20	0.20	Large formed components.	Unaffected.	Unaffected.	A few dark patches.	No change.	No change, condition very good, no corrosion and no rusting.
4 . . .	Cadmium.	0.30	0.60	Miscellaneous small machined components.	ditto.	ditto.	Unaffected.	Unaffected.	A little darkening in colour, generally unaffected.

required, troubles arise from pick-up of the coating by the electrode and from sticking of the electrode to the work. Vaporisation of the coating with resultant sputtering or "blow-out" from the welded spot may also be experienced.

Under the present subject, it is not opportune to discuss the methods of determining spot-weldability, but it is apt to quote comparative merits, as far as they are known to date :—

With zinc plating, up to 500 welds can be obtained before re-cleaning of electrodes is essential. The welds are sound, of good form (lozenge shaped in cross section), and of strength 800–1,100 lb.

With cadmium plating, sound welds of good shape and strength (1,100–1,200 lb.) can be obtained, but due to serious pick-up and sticking, up to 50 welds only can be obtained before retrueing the electrodes.

With tin/zinc alloy platings, only a restricted amount

of work has been performed. Strength of welds is very good (1,800–2,000 lb.). Sticking troubles are pronounced at the start of the run but rapidly improve, and the indications are that tin/zinc will respond to spot welding as well as zinc plating itself. Despite the high-strength value of the welds, rather poor shape (in cross section), "earring" cavities, and porosity are encountered. Further experience is required to eliminate this apparent defect.

The tin/zinc alloy platings are relatively new to industry, and extended usage is required before they can be fully appreciated in their proper perspective. The data presented in the foregoing is limited, but it establishes tin/zinc in a similar position to zinc and cadmium for the protection of iron and steel components, close to cadmium for resistance to damp conditions and ease of solderability, and superior to cadmium and close to zinc for spot welding.

Costing and Modern Accounting Methods in the Metal Industries

I—Basis for Application of Systems of Control

By S. Howard Withey, F.Comm.A.

The value and importance of the application to industry of modern costing methods are now widely recognised. In a series of articles on the subject, the author will discuss various systems of check and control. As the basis on which all accounting and costing records are made, this first article concerns methods of dealing with incoming orders.

ALTHOUGH fuel can often be saved by organised temperature control and the use of suitable thermostats, and attendant labour can sometimes be cut to the absolute minimum by the installation of furnaces which can be pre-set to give any desired time-temperature cycle with reliability, the demand for higher wages to meet increased living costs and the movement in the prices of certain raw materials combine to render imperative the maintenance of effective methods of accounting and costing, and in these articles it is proposed to outline various systems of internal check and control with the object of assisting metal traders, firms and companies to decide the most appropriate basis upon

which their records and statistics should be compiled.

Each works and mill has problems peculiar to itself and, of course, some engineering machinery and plant does not readily conform to a pre-conceived design. However, the exacting demands of modern metallurgy necessitate the application of the most up-to-date technique and research in the drive for higher performance and, while manufacturing processes and conditions vary considerably, the value and importance of accurate book-keeping and costing are now universally recognised and the establishment of modern methods of accounting enables managements to make modifications or extensions to existing plants where these are shown to be

Periodic statements showing comparative costs now usually include data relating to the number of orders received (less cancellations), the orders delivered (less any sales returns), and the orders remaining unfulfilled, and give both the value and the tonnage of output. Against the monetary value of the production, and that for the corresponding period of the preceding year, are debited the labour charges, manufacturing expenses, works charges and the general charges, the manufacturing expenses being classified under such heads as fuel, power, water, lighting, repairs, etc. The amount by which the credits exceed the total of the debits (including prime cost) represents the amount of profit made, and for purposes of comparison and control it is advisable to calculate the percentage relation which each group of expenses bears to the total turnover.

The basis for all accounting and costing records is, of course, the orders received, and effective methods are now being adopted for creating and stimulating new and repeat orders. Customers who are unable to obtain delivery of the material ordered may be offered a substitute involving little or no alterations of tools or design, but many order forms state that no responsibility will be accepted in respect of material sent that is not in strict conformity with specification, and usually contain a request that the number of the order be quoted on the invoice and other debiting documents.

All orders and instructions received should be dealt with in a systematic manner as part of the daily routine and some traders prefer to set down all details on loose printed sheets. Until such time as the job has been completed or the materials supplied, these sheets are

This may reduce the volume of clerical work to some extent, particularly in a small office, and while loose forms of one kind or another have now become a practical necessity, experience has proved that, when loose sheets are used for recording orders obtained, some of them get filed away before all instructions have been properly carried out or before the full charging prices have been debited in the ledger. By keeping a duplicate book comprising thin tissue leaves, the orders can be written out on the pen or pencil carbon-copy principle (a separate sheet being used for each distinct order) and the original handed to the person or transferred to the department immediately concerned in the execution of the particular order, and an authentic copy retained in the book. Directly a job has been completed, both the original and the copy can be cancelled, and if a money column is ruled down the right-hand margin of each page of the duplicate book the charging prices can be inserted and posted direct to the debit of the respective personal accounts kept in the sales or customers' ledger. If more than one carbon copy is considered necessary or desirable, a manifold order book should be kept on the same lines.

When all matters are taken into consideration, the most satisfactory method of recording orders in the metal industries consists of entering all essential details in a special bound book, thereby avoiding the possibility of obligations and arrangements being overlooked and conveying all the information needed by the staff in regard to specific jobs and contracts entered into. Although not in the strict sense an account book, for it is outside the scope of the debit and credit principle of modern book-keeping, the order book will contain a mass of useful information needed to compile accurate accounts and costs and should be kept neatly and up to date. Each entry should show the date on which the order came to hand, the name and address of the buyer, a detailed description of the latter's requirements and the agreed rate or price, also a reference to the plant or machinery to be used. These columns can usually be filled in without delay and if any unusual arrangements in the matter of delivery have been made, a note of these can be made in a "Remarks" column. To meet any requirements of a special nature, other columns may be needed, and when an order has been fulfilled it will be necessary to enter the date of delivery or supply, a full description of the goods, articles, materials or stores forwarded, and the charging out price, or cash book folio, as the case may be. A good general style of ruling for the book, and one capable of easy modification, is indicated below :—

ORDERS RECEIVED (Metals)

METALLURGIA

Developments in Alloy Steels

By T. H. Arnold, F.I.M. and C. V. Mills, Assoc.Met., A.I.M.

Research Department, Messrs. Hadfields, Ltd., Sheffield

Within the limits of a short article it is difficult to give an adequate picture of the progress made in alloy steel metallurgy to meet the ever-increasing demands of industry. In this review, therefore, the authors focus attention on some development aspects concerned with steels for high-temperature service, resistance to corrosion, and to wear. In addition, reference is made to interesting developments outside these fields.

WITH regard to commercially available alloy steels, the progress which has been made during the past year is essentially in respect of processing and the further investigation of the properties of certain particular compositions and their modified types. These features are related to the demands of the engineer arising from design development in industry in general and in the field of high-temperature engineering in particular. In a brief review of this nature a comprehensive survey has not been intended and attention is focused on steels for high-temperature applications, corrosion resistance, materials having high resistance to wear and some examples of interesting developments outside these fields.

Steels for High-temperature Applications

No special advances can be recorded with regard to resistance to scaling, but the presence of sigma phase in many alloy steels used for this purpose is still under review since the embrittling effect of this phase can be dangerous under certain conditions of stress during fabrication and in service.

Very considerable activity has been maintained with regard to the investigation and improvement of the creep properties of steels for high-temperature applications. Although research on the austenitic compositions has continued, the emphasis seems to be moving to the so-called ferritic types, and investigation is proceeding at an accelerated rate on this class of steels. The trend towards cooling of certain components of the gas turbine on the part of some engine builders is one reason for the enthusiasm attending the efforts to modify and improve the ferritic steels which are used. Apart from reduced cost, lower coefficient of expansion and easier machinability are factors which have naturally influenced designers in this connection. There is also the metallurgical aspect to bear in mind, that the ferritic steels are much less difficult to forge and lend themselves to reasonably easy production of sound forgings.

Two important applications for the creep-resisting steels which have been gaining wider attention are the rotors for gas turbines for land installations and marine purposes. The creep tests which are called for to provide data for these purposes are of a much longer duration—of the order of 10,000 hours—than those required by the aircraft designers and, as there are no reliable accelerated tests to give this information, the longer time tests are tending to increase the difficulties in the development of these alloys. Such alloys will find ready application in industry and many engineering projects. The hot extrusion of metals is an example of the potential use of such alloy steels to a process which demands good high-temperature properties for the tools

employed. Another example occurs in petroleum refining since this rapidly expanding industry, with its numerous products, uses large quantities of chromium-molybdenum steels.

The field of high strength ferritic alloy steels is being studied by The British Electrical and Allied Industries Research Association Committee J/E dealing with "Steels for High Temperatures." Further, systematic study in several industrial research laboratories is being applied to the influence on creep properties of the percentage of particular alloying elements and their ratio one to the other with varying carbon contents. The more usual of these alloying elements may produce under given conditions of heat-treatment carbides and perhaps inter-metallic compounds, the amount and distribution of which may have a pronounced influence on the high-temperature properties. Attempts to identify the complex micro constituents are being made by chemical and X-ray diffraction methods. The work of Goldschmidt¹ in which the discovery of a new carbide of chromium is described, and the paper by Wood and Rait² are typical examples of the efforts which are being made to obtain fundamental knowledge relating to the high-temperature properties of steels. There seems to be distinct promise that the work which is proceeding will result in the production of ferritic steels having better creep properties and improved resistance to scaling than those already in existence and thereby narrow the gap between the limiting temperature for ferritic steels and that at which austenitic steels become essential.

Corrosion Resistance

Numerous research projects are engaging the attention of the Corrosion Committee of the British Iron and Steel Research Association, but these in the main appear to be concerned with the accumulation of reliable data on established steels and the effect of surface treatment rather than the development of fundamentally new steel compositions.

An investigation has been completed this year in which a number of alloy steels were exposed to marine corrosion at Whitemans Bay, Freetown, Sierra Leone. The water at this location was estuarine, giving rise to extremely corrosive conditions.

The results of these exposure tests are given in Table I and a photograph illustrating the appearance of the specimens after they had been cleaned free from marine growths and corrosion products is shown in Fig. 1. This investigation was initiated by Messrs. Hadfields, Ltd., and the conclusion drawn from a consideration of the loss in weight results and the surface condition in

¹ Goldschmidt, H. J., *Nature*, No. 4136, Nov. 27, 1948, p. 855.

² Wood, G., and Rait, J. R., *Iron and Coal Trades Rev.*, Feb. 4 and 11, 1949.

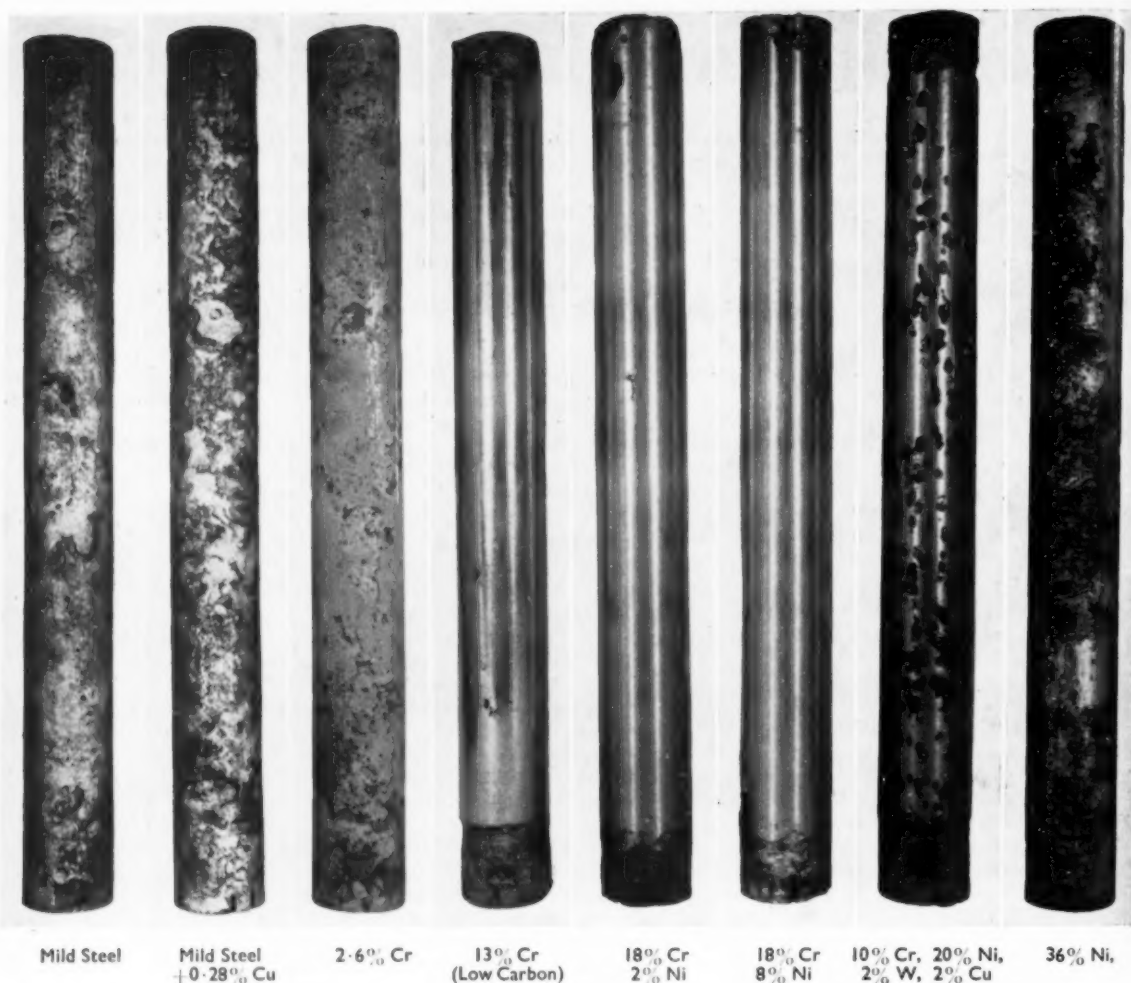


Fig. 1.—Specimens of various steels after subjection to corrosion in the sea at Freetown, Sierra Leone, and subsequently cleaned free from marine growths and corrosion products.

TABLE I.—CORROSION TESTS ON STEEL SPECIMENS COMPLETELY IMMERSED IN SEA WATER AT FREETOWN, SIERRA LEONE
The results are given as rates of loss by corrosion related to that of Mild Steel (= 100)

	Relative Corrosion Rates
Mild Steel C 0.24%	100
Copper-bearing Mild Steel Cu 0.28%	112
Mild 2.6% Cr Steel	65
Low Carbon 13% Chromium Steel	80
18% Chromium, 2% Nickel Steel	57
18% Chromium, 8% Nickel Steel	33
10% Chromium, 20% Nickel, 2% Tungsten, 2% Copper Steel	65
36% Nickel Steel	46

respect of the distribution and depth of pits, which are the characteristic of some of the more highly alloyed steels, was that the use of the low carbon 2½% chromium steel would prove to have economic advantages under conditions such as those operating at Freetown. This conclusion substantiates previous experience gained in tests conducted on the River Nile and in estuarine waters in East Africa, and confirms results which had been obtained in the U.S.A. on similar materials. In a report to the Industrial Waters (Corrosion) Sub-Committee of

B.I.S.R.A. Dr. Hudson refers to the foregoing, and also reports results of tests which he himself has carried out. The indications from his series of tests are also that increased resistance to corrosion is obtained by the addition of 3% chromium to mild steel.

The use of clad materials for corrosion resistance will, in the majority of cases, no doubt be determined by the question of cost, but on the other hand there are circumstances where the use of clad steel is justifiable on technical grounds. There are many instances where a corrosion resistant surface is necessary on one side only in which clad material has been employed with excellent results. The welding of these clad materials presents a problem which has necessitated much work.

The phosphating of steel surfaces has received attention from the point of view of corrosion resistance. Such surfaces are reported to give a moderate resistance for a short time but not to offer any prolonged benefit. They do, however, act as an excellent base for paints.

About three years ago great interest was shown in America in the possible injection of oxygen for the removal of carbon from high-chromium steel melts, in

particular 18/8 stainless steel. A considerable amount of investigation has continued to be carried out and the detailed physical chemistry of the process has been described by D. C. Hilty.^{3,4} More recently in this country an active interest has been taken in this project by a number of alloy steel makers, and an organised investigation of the process is now being carried out by the Electric Process Sub-Committee of B.I.S.R.A.

Generally speaking serious consideration of this process has been promoted for two reasons. One of these is the economic aspect based on a reduction of fuel costs as the primary consideration; the second is directly related to the chemistry of the steelmaking operation and consists of concentrated oxygen additions to facilitate and accelerate the rate of carbon removal during the boiling period.

The practice has been applied to several types of furnaces, but these remarks will be confined to electric furnace steelmaking and the production of high chromium and chromium nickel stainless steels. Consideration of the manufacture of low-carbon stainless steels has been influenced by two factors—namely, economy effected by the use of chromium-containing scrap charges and the growing demand for specially low carbon compositions.

By suitable control of the furnace temperature and the introduction of the oxygen, carbon can be removed without serious loss of chromium, a relatively high temperature favouring this preferential carbon removal. The attainment of a carbon content of 0.07% and less is a decided advantage in securing maximum corrosion resistance in the austenitic types of stainless steel. A further advantage lies in the fact that a very low carbon content ensures greater freedom from possible weld decay or intergranular corrosion in these steels which may also have a stabilising element present such as niobium or titanium.

Developments in this direction are of importance in view of the great demand for stainless steel and its increasing application particularly to chemical engineering projects.

Wear Resistance

Activity in this direction has been noted chiefly in respect of securing resistance to abrasion by the deposition of hard-facing materials rather than by the introduction of any alloy steel whose hardness is obtained by direct hardening by conventional methods. In addition to hard surfacing by the electro-deposition method, the weld deposition of wear-resisting materials has made a pronounced contribution to the types of material available for resistance to erosion and abrasion. Improvement in the wear characteristics of manganese steel of the Hadfield type has been secured by the addition of small amounts of chromium or vanadium. These additions are designed to increase the initial hardness of the manganese steel wearing parts and thereby maintain dimensional accuracy under pressure in the early stages of service life until the characteristic work-hardening effect has been developed. Further developments refer to the surface treatment of steels with a weld deposit of tungsten carbide or other hard carbides in a suitable base. An example of this type of wear deposit is the use of austenitic manganese steel as the base to carry the hard carbides and this is the subject of a recent patent application by Hadfields, Ltd. This

wear-resisting material has been designed to resist at the same time both light and heavy abrasion which has for a long time constituted a problem in the handling of many types of minerals, as for example in earth working and rock crushing. It is well known that abrasion by some of the softer minerals is difficult to combat due to the fact that a work-hardened skin is not developed on the metals with which the minerals are in contact and as a result, wear by sliding friction can be very severe.

Refrigeration as a means of securing transformation of retained austenite and thereby more completely promoting the fully hardened condition of a quenched steel has now been practised for several years. A recent interesting application of this technique lies in the refrigeration of alloy case-hardening steels following cyanide hardening.⁵ The presence of nitrogen due to immersion of the steel in cyanide is stated to accentuate the normal tendency towards retention of austenite on quenching alloy steels. The claim is also made that wear tests confirm that a case produced by cyanide hardening has superior resistance to wear compared with a case of equivalent hardness conferred by pack or gas carburising methods. The suggested explanation is the greater resistance of nitrogen-rich martensite to softening on heating.

In this field of investigation, the actual mechanism of austenite-martensite transformation has received considerable attention and knowledge of the true cause of the hardness of martensite has been enlarged by recent work. Whilst this in itself may appear to be of academic interest, the application to scientifically controlled heat-treatment and cooling rates in particular, is most important in relation to mechanical properties and also to the quenching of articles usually considered dangerous due to a combination of composition and shape or profile. The visit of Professor Morris Cohen of the Massachusetts Institute of Technology to this country this year contributed greatly to the interest taken in the effect of sub-zero temperature treatments. As is well known, Prof. Cohen has published a considerable amount of work on the mechanism of the breakdown of austenite to martensite and great interest has been taken in his very interesting theories on this subject.*

Miscellaneous

In the field of weld-fabrication, progress has been made in the production of welds of high-tensile strength. High-tensile alloy steel metal arc welding electrodes can now be made available which provide a weld metal possessing inherent characteristics of high-tensile strength combined with good ductility. These tensile properties can be varied to a considerable degree by heat-treatment, thus satisfying individual requirements and opening up a new field in weld-fabrication or weld-rectification. Typical tensile tests obtained on such heat-treated all-weld-metal are as follows:—

Yield Point Tons/sq. in.	Max. Stress Tons/sq. in.	Elong. % on 1½ in.	Reduction of Area %	Brinell Hardness
60	73	21	45	330
50	55	21	60	260

In a paper to the Iron and Steel Institute⁶ Bardgett and Reeve describe the mechanical properties of molyb-

³ Hilty, D. C., *Journ. of Metals*, Feb., 1949, p. 91.

⁴ Hilty, D. C., *Journ. of Metals*, Sept., 1949, p. 20.

⁵ Waterfall, F. D., *Metallurgia*, Vol. 40, No. 235, May, 1949, p. 29.

⁶ Bardgett, W. E., and Reeve, L., *Journ. I.S.I.*, Vol. 163, Part 3, Nov., 1949, p. 277.

* A report of a lecture by Dr. Cohen, to a joint meeting of the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association, is published in the October, 1949, issue of this journal, in which he discussed the hardening and tempering of steel.—EDITOR.

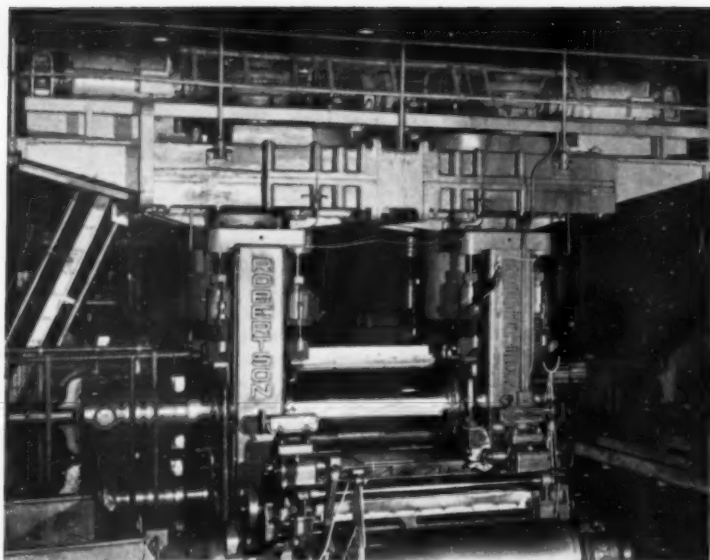


Fig. 2.—Two-high mill at the Banbury Works of the Northern Aluminium Co., Ltd., employing 30½ in. dia. × 61½ in. × 149½ in. forged and hardened steel "Hadura" rolls for the cold reduction and finishing of aluminium alloy strip. The body hardness of these rolls is 100/102 "C" type Shore.

TABLE II.—MECHANICAL PROPERTIES OF LOW CARBON, 0.5% Mo STEELS CONTAINING BORON

Analysis %					Heat-treatment	Yield stress tons/sq. in.	Max. stress tons/sq. in.	El %	R. of A. %	Izod ft.-lb.
C	Si	Mn	Mo	B						
<i>Forged</i> ^o					920° Air	17.4	32.2	37.0	68.0	85
0.13	0.28	0.43	0.46	—		35.9	42.1	25.0	63.6	80
0.14	0.26	0.45	0.54	0.002	950° Air	16.5	30.2	25.5	44.3	14
<i>Cast</i> [†]						32.9	42.0	11.0	22.0	46
0.14	0.14	0.61	0.57	0.001						
0.14	0.33	0.61	0.57	0.002						

* Extracted from "Mechanical properties of low-carbon, low-alloy steels containing boron," Bardgett and Reeve, *Ind. I.S.I.*, Nov., 1949.
† Hadfields, Ltd., Research Department.

denum steel to which a small percentage of boron has been added during the steelmaking process. From the numerous test results given, the presence of boron is shown to appreciably enhance the maximum stress and the yield stress. This steel is also stated to have excellent welding properties and has been registered as "Fortiweld." The work done by Bardgett and Reeve was confined to wrought material. At their invitation, however, the properties of this type of steel in cast form have been subsequently investigated by the company with which the writers of this article are associated. The test results, given in Table II, show that the advantages derived from the addition of boron to the wrought molybdenum steel are also secured in the case of the cast material.

It is difficult to study present-day technical publications without becoming aware of the number of references to continuous rolling and high-production rates in modern cold-rolling strip mills. The manufacture of fully hardened steel work rolls for such mills is a further example of progress in production technique of a metallurgical character. Such rolls are used for the cold rolling of all ferrous and non-ferrous metals and alloys. It is recognised that high-quality steel is a primary essential in the specialised procedure involved in making

rolls of this nature in order that they can successfully withstand the onerous conditions imposed in hardening and in operation. Surface finishes which are now being required by the cold-rolling industry are such that higher intrinsic roll hardness and absolute freedom from any surface imperfections are becoming a prime necessity. It is, therefore, important in this connection to record that during the current year rolls of no less than 30½ in. diameter and weighing nearly 10 tons each have been successfully made and put into service. They exhibit a uniform body hardness of 100/102 "C" type Shore hardness which represents approximately 105/109 on the Dial or Recording type instrument. These rolls are the largest and heaviest yet made in this country at this hardness level, and those who are familiar with the requirements necessitated by consideration of both manufacture and service will recognise that this is a technical achievement of a very high order. The photograph Fig. 2 shows a pair of highly finished "Hadura" rolls of the type operating in a British mill.

The B.S.F.A. to form a Research and Development Division

THE British Steel Founders' Association has long recognised the need for co-operative research to reduce manufacturing costs and improve quality, and that, if steel founders are to keep ahead of all foreign competition, they must lose no time in applying any new developments which can, with advantage, be applied in the steel founding process. The Association exists to ensure that the user of steel castings gets the best service of which the industry is capable. By establishing a Division for the purpose of organising the co-operative effort in the manufacturing field, faster progress can be made in the general development of the British steel foundry industry.

The Association's plans comprise the constitution of a separate Research and Development Division, the whole of whose resources will, if need be, be found by its member-firms. The primary object of the Division will be to provide its members with information vital to the continued improvement of productivity and, in the first place, it will concentrate on bridging the gap between established scientific knowledge and existing manufacturing processes, so that the best production techniques and most suitable materials can be made known to and used by all of its members.

The Association will function in a different way from other research bodies working on steel foundry problems, and it is intended to maintain the closest possible contact with them to ensure that no problems of importance to the industry are neglected.

The fact that the Division is, at the time of its inception, assured of the support of the vast majority of those engaged in the industry speaks well for the industry's determination to do its full share in recovering the country's position as the leading exporter of engineering products.

ALUMINIUM IN 1949

By E. D. Iliff, B.Sc.(Eng.)

Northern Aluminium Co. Ltd.



During the war the aluminium fabricating capacity in this country increased five-fold; when the war ended it was generally thought the industry would languish and shrink, but the expected trade recession became a boom, and to-day, of the metals, aluminium continues second to steel in industrial importance. Some of its technical aspects and applications are reviewed in this article.

The de Havilland "Comet" in the construction of which aluminium has a considerable part.

TO the aluminium industry war was a tremendous stimulant. World production shot up, and in this country fabricating capacity was increased five-fold in five years. It was generally expected that, deprived of this stimulus, the industry would languish and shrink. Events have proved this forecast to be quite inaccurate and, of metals, aluminium remains second only to steel in industrial importance.

Let us trace the course of events since June, 1945. At first there was a wild rush to make goods of all the many kinds which had virtually disappeared during the war. Availability often decided the choice of material, and aluminium, no longer required for aircraft, seemed an obvious choice. But plant, layout and personnel had to be reorganised to enable the change to be made from production of aircraft materials, predominantly heat treated, to the varying requirements of British industry struggling both to satisfy the home market and to comply with the urgent necessity to export. The aluminium bungalow, intended by a benevolent Government to kill two birds with one stone, by providing houses for homeless thousands and keeping the aluminium and aircraft industries from stagnation, helped considerably to tide over this period of change. There was also a considerable demand abroad for semi-fabricated aluminium, since much of the European capacity for manufacture had been destroyed. So the expected trade recession for aluminium became a boom, which has lasted up to the present. Prophecies were never more futile than now, so wisdom commends silence as to future industrial trends, and we shall concern ourselves only with the technical aspect.

Products

Alloys.—What developments have taken place in aluminium alloys? There are no startling advances to report, rather has the post-war period been one of consolidation and rationalisation. The Al-Zn-Mg-Cu alloys, which have gained a strong foothold in the aircraft industry, are still in the development stage so far as commercial applications are concerned. Their very high tensile strength is an asset for special applications,

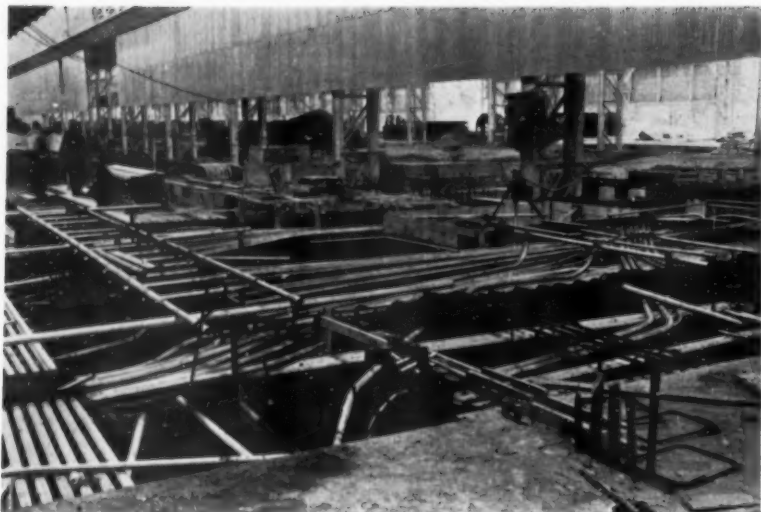
but these are limited because of the relatively low ductility and unimproved endurance of the alloys. For duties demanding strength and toughness the alloys in the AW.15 group still retain pride of place.

In sheet material there has, of course, been a big swing over from heat treated to strain-hardened alloys and, in volume of production, commercially pure aluminium vies with 1.25% manganese alloy for first place. Where greater strength is required the Al-Mg alloys take precedence, and heat-treated metal is used only in special cases, though a considerable tonnage is still employed in housing and aircraft.

With extrusions, too, the emphasis is less on high strength, decorative requirements being met largely with commercially pure aluminium, while for structural uses medium-strength heat-treated alloys, notably AW.10, are most in demand.

Sheet.—Total output of sheet to-day nearly equals the wartime peak, and shows the extent to which fabricators have been able to rearrange plant originally installed for the production of aircraft materials. This has not been easy. Outside the industry it is perhaps not realised that the rapid expansion of production in the years of the war was achieved by many makeshifts and extemporisations, and the plants built up in emergency were not often ideally arranged for economic operation. Reorganisation has had to be carried out with the minimum disruption of output, so that progress has been slow and is, even now, not quite complete. Apart from rationalisation of existing plant there has been considerable development, particularly in the rolling of plate for shipbuilding. Important schemes are also nearing completion for the large-scale production of sheet for building, packaging and other potentially vast fields of use.

Extrusions.—Extrusion plant installed during the war attained an output almost equal in tonnage to that of sheet. An appreciable proportion of this comprised heavy sections, such as wing spars, extruded by presses rated at 5,000 tons, of which no fewer than five have been installed. With the virtual cessation of aircraft production the demand for extrusions fell to less than a third of



Aluminum conduits in course of installation in machine foundations at the Rogerstone Works of Northern Aluminium Co., Ltd.

peak output, but by 1948 it had recovered to nearly half its maximum. The advantages of extrusions are becoming more widely appreciated, and their uses more diverse, hollow sections in particular being increasingly in demand. To find work for the largest presses is still a difficult problem, since it has to be admitted that only in exceptional circumstances can the cost of aluminium be justified in heavy structural engineering. Nevertheless some of the biggest sections ever extruded have been made in the last year or two, and not always for aircraft. The production of tubing of large diameter for oil pipe lines is work for the big presses which may well increase; already tubing 12 in. in diameter has been satisfactorily extruded.

Forgings and Castings.—The position of forging plant is less hopeful, and present output is still mainly dependent on aircraft as industrial applications of aluminium forgings seem to be few. Not so with castings, however. Light alloy foundries have felt the revival of ferrous competition, but have by no means succumbed. Output, though a little lower than in 1943, the peak year, is still far above pre-war level, when the naval construction programme provided substantial orders. Expansion of the aluminium alloy casting business is principally in the gravity die process, which permits competition with malleable iron in price and provides a more nearly finished article, thus saving on machining costs.

Argonarc Welding

The absorption of the available output of aluminium is evidence that experience of working and finishing processes is widely distributed throughout British industry. Conservatism is still encountered and also reluctance to undertake work which necessitates learning new techniques, but the conception of aluminium as the metal appropriate only to cooking utensils and aircraft is fast disappearing. There is, as always, a strong predisposition to judge aluminium on its response to working and assembly techniques employed with other industrial metals, especially steel, and this is a recurrent obstacle which has to be overcome in developing the uses

of aluminium. Joining is a particular problem, since it has always to be admitted that aluminium will not weld as readily as steel nor solder as satisfactorily as heavier non-ferrous metals. The recent introduction to this country of the argonarc process is a considerable step forward, and shows great promise of reducing aluminium's disadvantage in welding. The merits claimed for the process are that it effectively disperses the oxide film and positively prevents formation of oxide during welding. A sound joint is therefore made, and the absence of flux obviates troublesome cleansing. Welding proceeds rapidly, with the minimum heating of the zone surrounding the joint, so that softening of the metal on either side of the weld is avoided, and the welded article is stronger. British-made argonarc welding sets have only been available since early this year, so the process is not yet widely used here, and the present price of argon gas makes it relatively costly. As the demand for the gas increases its price can be expected to fall very considerably, and this will further extend the employment of the argonarc process.

Applications

The applications of aluminium are many and varied, and in each there are special problems and points of particular interest. Space will not permit more than a few brief comments on some of the principal fields.

Aircraft.—Credit for the very notable achievements in aircraft construction during the past few years is shared in no small measure by the aluminium industry. Fabricators never forget their special obligations as producers of the basic material of aircraft construction, and can claim to have co-operated to the full in the effort to capture world markets for British aeroplanes. At least three outstanding long-range aircraft owe much to the use of weight-controlled sheet and extrusions of special accuracy. Normal manufacturing limits and tolerances go by the board, and the greatest care and attention is devoted to work which would not be accepted from any other source. This applies in particular to sheet to DTD.687 and extrusions to DTD.363A and DTD.683, which are difficult to fabricate and have a slow rate of production, and thus occupy plant which might be employed more profitably on easier work. But the value of the experience gained is not unappreciated, and demands, which often at first seem impracticable, stimulate and provoke new attainments in production technique.

Shipbuilding.—In other forms of transport, as the need is less vital so is the demand less certain and also less exacting. In shipbuilding, to be sure, there is always the possibility of larger and heavier plates being required than can be produced in most mills, but this is as yet more of a hope than an anxiety. The time has not yet come when hull plates are much in demand, and the more modest requirements of superstructure plates

and sections do not tax manufacturing resources. Sections are usually in AW.10, but where severe forming is required one of the Al-Mg alloys may be supplied instead. These are the alloys generally used for plating and panning. In some circumstances the heat-treatable alloy Noral 65S has particular advantages for both plate and sections.

The acceptance of aluminium alloys by Lloyds Register last year was an important event in the history of both the industries concerned and marked a considerable increase in the use of light metals in ships. There has been no particularly dramatic instance, but many small orders are received for superstructures, fish holds, boats and launches. Shipbuilding is one of the marginal fields of development for aluminium: "marginal" because a slight decrease in price could bring a disproportionate increase in demand, and any appreciable rise in cost is likely to curtail drastically the interest of shipowners and shipbuilders in aluminium.

Railways.—Introduction of aluminium into rolling stock has always been uphill work and, though its use as a medium of decoration in passenger trains has increased, progress in structural applications is rather disappointing. Cost is, of course, the principal obstacle, and no very strong inducement to lighten is recognised. Freight charges take no account of the tare of the wagon, and

although lightness might enable existing locomotives to draw longer trains, platforms and loading bays would have to be lengthened to accommodate them. Yet lightening offers many advantages which, though they cannot always be evaluated in terms of money, are none the less real: improved acceleration, retardation and gradient climbing; greater stability; reduced wear and tear; less noise. These have been considered sufficient to justify the placing of an order for lightweight trains for the London Underground, where faster schedules mean greater revenue. On main lines, however, direct savings in operating costs are the principal concern, and the capital charge is usually estimated to more than offset any gains. This seems rather illogical and raises a doubt as to whether the overall cost of construction in aluminium is fairly calculated. In the



Courtesy of Brooke Marine, Ltd.

The 450-ton motor trawler "Jorundur," built by Brooke Marine, Ltd. for Icelandic owners. The superstructure and funnel are of Noral 65S plate and Noral 51S sections; the fishroom is lined with Noral M57S sheet, and equipped with Noral 51S extruded stanchions and poundboards.



The fishroom of the trawler "Jorundur" showing the extruded poundboards and stanchions.



A 40-ton Wellman crane, one of nine aluminium alloy cranes in the Rogerstone Works of Northern Aluminium Co., Ltd.



Courtesy of The Bristol Aeroplane Co. (Housing), Ltd.

Prefabricated aluminium school buildings.

absence of production experience, estimation of costs is bound to be largely guesswork, and it seems that the price of the finished wagon or coach is sometimes assumed to be in proportion to material costs. This is not at all a fair assumption, and, if the vehicle is designed specifically in aluminium and appropriate assembly methods are used, there is no reason why the cost of construction should be high. Builders are, not unnaturally, reluctant to obtain new equipment and undertake new methods unless there is very good reason to do so, and the case cannot be proved without fair trial. However, British Railways are still showing interest in aluminium construction, particularly of passenger coaches.

Road Transport.—In road transport the Road Fund Tax provides a potent inducement to limit unladen weight of goods vehicles and, though an all-light-metal body may cost twice as much as a timber-and-steel one, it is recognised that its life is more than three times as long. Many bodybuilders, large and small, are using aluminium, and, as experience accumulates, better designs and better methods of construction are evolved. With passenger vehicles the starting point for use of aluminium is, naturally, the panelling, moulding and decoration. There is no artificial inducement to restrict weight since seating capacity determines taxation liability. The case for the structural employment of aluminium is therefore technical, and rests on economy of operation, improvement of stability, reduction in maintenance costs and increase in length of life; and there has been substantial progress. The chassis-less type has not yet emerged on a large scale, and presents some problems. Chief of these is that work normally undertaken by chassis manufacturers—assembly of engine, transmission, wheels and braking system—would be thrown upon the bodybuilder and, moreover, new methods of building, more akin to aircraft construction, would have to be adopted. A good deal of exploratory work is proceeding, but it is too early to forecast the outcome.

Mining.—A much newer field of development is that of coal mining. The tonnage of aluminium used in collieries up to the present is disappointingly small, and it is evident that no easy progress is to be expected. The biggest potential for aluminium probably lies in



Courtesy of Acrow (Engineers), Ltd.

Aluminium scaffolding of the London Coliseum.

roof supports of various kinds, though here it is in direct competition with steel which costs less than a quarter as much. With a high wage level, speed and ease of work can go far to offset costs of equipment, but with such a disparity the case has to be very well established. It is interesting to note that some types of roof support are required to stand severe deformation and restraughtening several times without failure, and that a strain-hardening alloy satisfies these requirements best. It is not too much to say that most items of coal-winning equipment would benefit from utilisation of aluminium alloys to ease handling and increase mobility, while conveyors, tubs, skips, cages, winding machinery, washing and screening plant can all use aluminium with advantage, and are reasonably certain eventually to do so.

Electrical Industry.—One of the natural fields of use of aluminium is the electrical industry, and here again progress is slow, though steady. The aluminium-sheathed electric underground cable appeared on the market last year and is being produced by more than one manufacturer. Direct extrusion over the insulation, which has been the subject of much experimentation, is the ultimate aim and will, it is expected, be achieved commercially in the near future. Aluminium wire and tape—both AW.4 and AW.10—are being used for armoring of underground and flexible cables, with obvious benefits both in weight-reduction and improvement of flexibility. As a busbar material aluminium has, of course, been used for many years, and is making headway now, but very slowly in view of its big price advantage, due, presumably, to conservatism on the part of electrical engineers. The merits of aluminium conduit should ensure a ready sale, but some reluctance to give it a trial has been evident. In price it is less than the best quality steel, but in recent years the impossibility of obtaining conduit of the best quality has apparently rendered cheaper grades acceptable. The ease with which aluminium conduit can be handled, cut, screwed and set reduces installation time very

appreciably and if this is taken into consideration the overall cost is seen to be much less than that of other types of metallic conduit of comparable merit.

Structural Engineering.—The potentialities of aluminium alloys in structural engineering are largely restricted to mobile structures such as cranes, excavator booms, and the like, though portability to site is worthy of consideration. This was one of the advantages of aluminium construction of the bascule bridge erected last year at Sunderland, when complete leaves of the bridge were assembled in the yard of the builders and transported to site by sea. Ease of erection is another favourable point, appreciated especially with roof trusses and cranes. The last few years have seen the erection of a large number of aluminium roof trusses, both in permanent and temporary buildings, and nine new aluminium alloy cranes have been installed in Northern Aluminium Co's works extensions at Rogerstone. For covering factory buildings aluminium corrugated sheet is increasingly used, its resistance to industrial atmospheres being specially valuable. Prefabrication has much to commend it in these days of shortage of building labour and materials, and the prefabricated school buildings which have been erected in many parts of the country in the past year or so have solved the problem of several education authorities. The market for aluminium alloy scaffold tubes, introduced since the war, was thought by many to be due only to shortage of steel, though the possibility of a small sustained demand for special circumstances was admitted. The fact is, however, that aluminium scaffold tubing, though costing more than twice as much as steel, has established itself strictly on its merits, and at least 5 million ft., and probably much more, is sold each year. This provides very useful work for extrusion presses.

Agriculture.—Aluminium cannot yet claim to have established a firm foothold in farming, where first cost is watched very closely and little is taken on trust. It is to be expected that development here will be slow, but sure. The timber shortage has prompted the use of aluminium for poultry houses, but at least one type—the "Sarum Igloo"—has been specifically designed in aluminium and shows originality and real skill in using the new medium. Following the success of this poultry house, an aluminium pigsty built on similar lines has been put on the market.

Packaging.—The advantages of aluminium as a packaging material are well known and accepted. In recent years the supply of thin gauge aluminium for the metal container industry has not equalled the demand, so aluminium has mainly been used where its sales appeal is most effective—in packaging cosmetics and household goods. As with tinsplate, in wet packs some form of protection may be necessary—anodising or lacquer, or both—and work is proceeding to establish the most satisfactory methods. Increase in production and reduction in price of aluminium container sheet are possibilities which are being watched with interest by the metal container industry, and Northern Aluminium's new semi-continuous rolling mill, now nearing completion



Courtesy of A. P. Components, Ltd.

"Sarum Igloo" poultry house and run constructed in Noral 3S sheet.

at Rogerstone, Mon., is designed to promote and to cater for just such an eventuality. This new mill will also produce corrugated sheet, both for industrial buildings in this country and for direct export, and flat or coiled sheet for a wide variety of types of sheet-metal work, from domestic bread bins to poultry appliances and motor-car body panels.

Space will not permit further detailing of all the possible, probable or optimistic prospects of extending the employment of aluminium, and it only remains to say that aluminium has become, and will remain, an essential raw material of industry, the uses of which are infinite.

Two New Tube Investment Subsidiaries in South Africa

TUBE INVESTMENTS announces the formation of a new subsidiary, TI South Africa (Pty.), Ltd., to assist generally in the promotion of the business interests of its subsidiary companies in that country. Major-General Sir Francis de Guingand, K.B.E., C.B., D.S.O., has been appointed resident Chairman and Managing Director of the company.

Tube Investments also announces the acquisition of the factory, plant, and equipment of the Ace Cycle & Engineering Co., Ltd., of Springs, near Johannesburg. This resulted from an offer made by the Chairman of Tube Investments, Mr. I. A. R. Stedeford, during a recent visit to South Africa, on behalf of a further subsidiary, TI Cycles (South Africa), Ltd., then in formation. The offer was accepted by shareholders, and Tube Investments' technicians are now at the works at Springs, which are being planned to produce cycles specially suited for South African conditions.

TI Cycles (South Africa), Ltd., now formed, is a public company, with an authorised capital of £500,000, made up of:—250,000 5% Cumulative Redeemable Preference Shares of £1 each—£250,000. 1,000,000 Ordinary Shares of 5s. each—£250,000.

The directors of the company are I. A. R. Stedeford, Esq., N.G. Lancaster, Esq., W. F. Withers, Esq., Major-General Sir Francis de Guingand, K.B.E., C.B., D.S.O., (Chairman) and Sir George W. Albu, Bart.

Progress in High Duty and Alloy Cast Iron

By A. B. Everest, Ph.D., F.I.M.

The Mond Nickel Company Limited, London.

Although primary consideration is given to the outstanding development of the spheroidal graphite cast irons, the author emphasises that progress with other types of high-duty cast irons is continuous, as the needs of modern engineering practice become more exacting, and briefly refers to some of these types.

PRIDE of place in any article written at this time on the subject of cast iron must be given to the realisation on a practical and economic scale of the production of grey iron castings with the graphite present in the form of spheroids or nodules in place of the more conventional flake type in the metal as cast in the foundry. Whilst this is, undoubtedly, the major development in this field in our time, reference will also be made to the extending use of special types of alloy cast iron to meet the increasing demands of engineering practice.

Graphite in Cast Iron

Since the earliest days of metallography it has been recognised that the characteristic structure of grey cast iron consists of a steel-like matrix broken up by carbon in the form of graphite which separates in the metal during cooling. This graphite normally assumes the form of flakes (see Fig. 1). These flakes present a relatively large area for the volume they occupy, and the edges of the flakes are generally sharp. A glance at the microstructure will explain at once why cast iron is a weak and brittle material. The graphite flakes are devoid of any useful mechanical strength, and their effect is to break up the continuity of the metal matrix. Furthermore, the sharp edges of the flakes are sources of weakness, in that they provide innumerable notches throughout the metal, each of which markedly reduces its shock resistance, besides introducing innumerable points of stress concentration. The deleterious effect of the graphite flakes on the properties of the metal can



Fig. 1.—Flake graphite in normal grey cast iron. Unetched $\times 100$.

more readily be appreciated if, for example, in Fig. 1, lines of stress are imagined superimposed on the structure. These lines will be deflected at each flake, and must take a tortuous path around the flakes with high concentration at many points.

The results of this on the properties of a casting are well known. The matrix of the metal has a tensile strength of some 60 tons per sq. in., with a high degree of toughness and elasticity. The effect of the graphite flakes, however, in the metal reduces the strength, often to a figure as low as 10 tons per sq. in., with shock resistance reduced to negligible values and no measurable ductility—properties which are associated with the common domestic type of cast iron which, at least in thin sections, shatters if dropped on a hard floor. It must be realised that in this consideration we are concerned primarily with the effect of the graphite on the mechanical properties of the metal. There are many occasions when coarse flake graphite is desirable, but irons with such a structure would not be classed as high duty.

Malleable Cast Iron

Early in the history of ferrous metallurgy it was recognised that, if the carbon in cast iron is retained in the combined form, that is the iron is white as cast, then, with suitable compositions, by a special type of annealing heat treatment known as malleabilising, the graphite can be made to separate gradually from the metal, and under these conditions it assumes a nodular form, or as compact clusters of fine graphite. The beneficial effect of rendering the graphite nodular is seen at once in the enhanced properties of malleable cast iron. According to the processes used, the tensile strength of malleable varies from about 20–30 tons per sq. in., and the iron has a measurable elongation of 5% or upwards; of greatest importance is, however, its increased toughness or shock resistance. For many years past foundrymen have realised that there would be a great advantage in any process which would lead to the production of grey cast iron, as cast, which would have the properties of malleable, as a result of the graphite being in a more compact form. It is this goal which has now in recent times been realised.

During the war, Morrogh of the B.C.I.R.A. and his co-workers made rapid progress in their studies of the fundamentals covering the formation of graphite in cast irons. In this connection he presented an interesting paper¹ in which were described successful efforts to control the graphite form in nickel-carbon and cobalt-carbon alloys. In this the workers showed that they

¹ "Graphite-Formation in Cast Irons and Nickel-Carbon and Cobalt-Carbon Alloys," Morrogh, H., and Williams, W. J. *Jnl. Iron and Steel Inst.*, 1917, 155, 321–71.

could, at will, make the carbon separate on casting either as flakes or spheroids. This was effected by additions which had a high affinity for the sulphur in the metal.

Nodular Graphite Cast Iron—The Cerium Process

It was a logical step from this work to the development of nodular graphite cast iron, and the element found effective was cerium, as described in a later paper². The B.C.I.R.A. carried out considerable development work on the cerium treated irons, and elaborated the conditions under which cerium would work. They published results of their studies of the properties of these irons³.

Spheroidal Graphite Cast Iron—The Magnesium Process

During the course of discussions of papers by Morrogh and his co-workers (see, for example, reference 2), announcements were made both in Great Britain and the U.S.A. of the development of a new process for the production of cast iron with spheroidal graphite, which had been evolved after many years of research work in the laboratories of The International Nickel Company in the U.S.A. The basis of this work was the discovery of effective methods of introducing magnesium.

Following this announcement intensive work was carried out in many research laboratories and in foundries on both these processes. It is perhaps too early at this stage to say what the final outcome of these developments will be, but it appears at the present time that treatment with magnesium has advantages over the cerium process in respect of adaptability, reliability and cost. It is for these reasons that the magnesium process is now making rapid headway in its commercial development for engineering castings.

An article, giving details of the new irons and their properties appeared in *The Iron Age*⁴, and subsequently an article was published in the technical press in Great Britain by The Mond Nickel Company⁵. Since the

earliest announcement of the development, intense interest has been shown in the new type iron, and a number of other papers have appeared in different countries on the subject.

This is not the place to repeat details of the new process for the production of spheroidal graphite cast iron. It is sufficient to say, however, that the magnesium process can be applied with great advantage to all engineering types of grey cast iron produced in the foundry. For optimum results, however, careful control over composition is essential. The process is simple and safe, and can be applied in ordinary foundry practice without interfering with normal production. The foundry properties of the metal are good, although special precautions are necessary to meet the particular characteristics of the new iron, such, for example, as its rather higher shrinkage as compared to ordinary grey iron. Experience to date, however, has shown that it can be applied without substantial modification, to the normal types of castings made in the foundry. The fluidity of the metal is good, and it has now successfully been applied to the production of single castings up to 20 tons weight on the one hand, and to light repetition castings on the other, where production runs of many thousands have been successfully made.

The production of the new type cast iron has been covered by patent applications in the leading industrial countries of the world. It is of interest to note that in recent weeks the U.S.A. patents have been granted. British patent applications have also been accepted under numbers 630,070, 630,093 and 630,099.

The new type iron is manufactured under licence. Already some 50 licences have been granted in the U.S.A., where individual foundries are now producing up to 100 tons of the new iron per day. Four licences have already been granted in Great Britain, and a number of others will be completed in the near future. Castings in the new type irons are now coming into production in this country and will be available for a variety of purposes within the next few months.

The Properties of Spheroidal Graphite Cast Iron

The advantages of cast iron in which the graphite occurs in the nodular or spheroidal form have already been referred to above. The structure of the new type of cast iron is shown in micros, Figs. 2 and 3, and it

Fig. 2.—Spheroidal graphite developed by magnesium treatment of iron shown in Fig. 1. Unetched $\times 100$

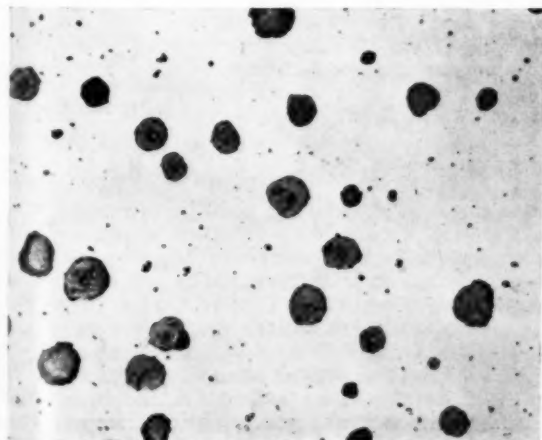
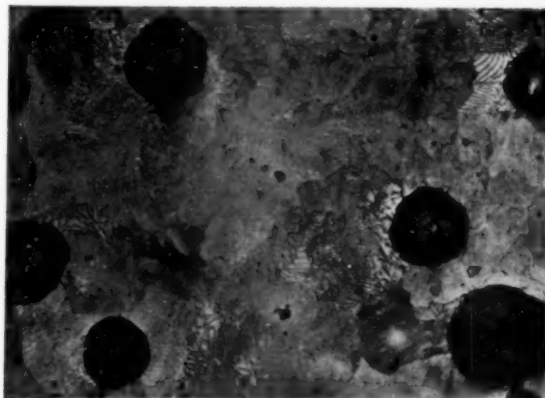


Fig. 3.—Spheroidal graphite cast iron. Etched $\times 250$



will at once be appreciated that from the mechanical point of view the structure is markedly superior to the conventional form, as shown in Fig. 1. Detailed properties have been quoted in the papers referred to above. They may briefly be summed up by mentioning that the new spheroidal graphite cast iron, in the cast condition, has a tensile strength of over 40 tons per sq. in., whilst under particularly favourable conditions much higher strengths may be achieved. As cast, this tensile strength is associated with a high yield point, and elongation generally from 2-5% for irons with a pearlitic matrix. Of greater importance, however, is the marked shock resistance shown by the iron as measured by an impact test; it is usually five to ten times that of ordinary iron.

Detailed studies of the special properties and service behaviour of the iron are being made, but sufficient data are already available to show that the new iron has, as would be expected, superior properties in every direction studied (^{4, 5}). From the practical point of view the iron is readily machinable. Its service properties, such as resistance to wear and heat, promise from first results, to be good. Data are at present being obtained on its corrosion resistance.

Heat Treatment

The new material, as cast, may be subjected to the conventional types of heat treatment; thus quenching and tempering may be employed to increase hardness and wear resistance and are effective in giving even higher mechanical strength. Normalising and tempering are also advantageous. Of the greatest interest and importance, however, is the fact that the new irons may readily be annealed to break down the pearlitic matrix to ferrite. Annealing for, say, five to eight hours will produce a complete breakdown of the matrix, leading to a material with properties superior to those of malleable cast iron. The tensile strength of the annealed metal is generally of the order of 30/35 tons per sq. in., and this is associated with an elongation in the tensile test of from 10% to 20%. Toughness is simultaneously increased as shown by the impact test.

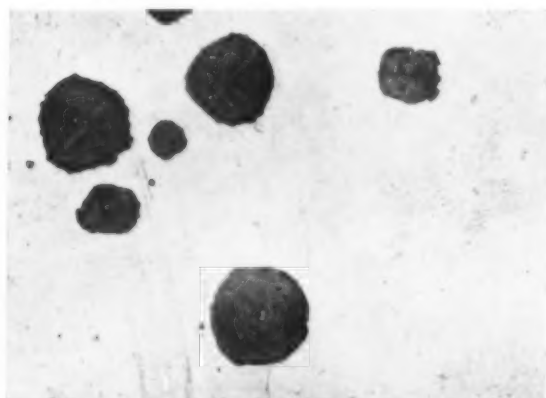


Fig. 4.—As for Fig. 3, after annealing to give a substantially ferritic matrix. Etched $\times 250$

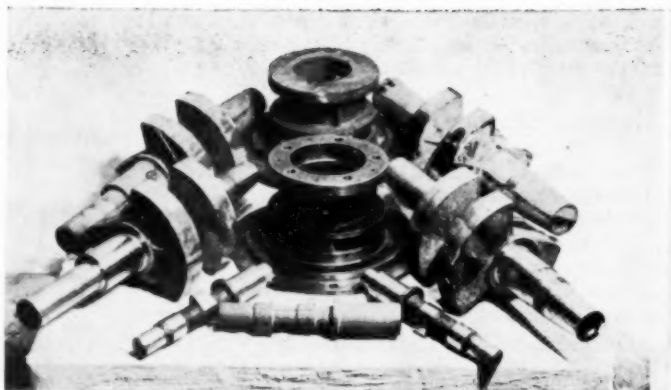


Fig. 5.—Group of castings in Acicular Cast Iron, showing crankshafts, camshafts and wheel hubs as cast and machined.

By courtesy of Douglas (Kingswood) Ltd.

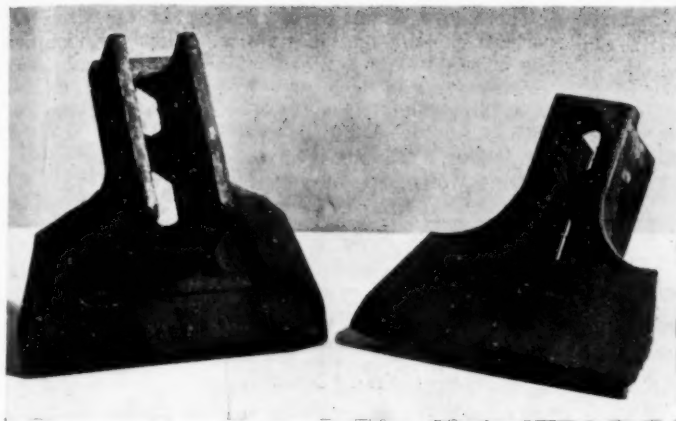
The micro-structure of a fully annealed sample is shown in Fig. 4, in which it will be noted that the pearlitic matrix of the metal in Fig. 3 has broken down, and that the carbon has precipitated on to the existing spheroids.

Special Types

The magnesium process is not restricted to normal grey cast iron, but can be used in conjunction with alloys in irons having special matrix structures; thus it is now established that a remarkable improvement in the mechanical properties of the austenitic cast irons can readily be obtained, and spheroidal graphite offers also interesting modifications in the properties of the acicular and other special types of cast iron.

Applications

The world's technical press has, with justification, heralded the development of these new types of cast iron as the outstanding metallurgical development of our age. The main centre of activity has shifted from the Research Laboratory to the Foundry, where the production of the iron is now being established. In the U.S.A. interest has already moved on to the engineering drawing office, where the application of the iron is being intensively studied. From the data given above, it is clear that the new type of cast iron offers engineers material of the greatest importance and value in engineering design. The new metal can effectively replace some steel castings on the one hand, and malleable on the other. From this point of view, the most important characteristic of the new material as compared with conventional cast iron, is its improved toughness, and already the new irons are being adopted for details of automobile construction and agricultural equipment where, owing to rough usage, something tougher than cast iron is required. From the economic angle the new material can compete favourably both with steel and malleable iron. There are innumerable fields, including that of marine castings, where cast iron is desired, but is often replaced by cast steel or by fabrications, owing to its brittleness. In this connection, the new type of iron will restore confidence in iron castings. For the production of many castings, such as pipes, the substantial reduction in weight, made possible by the high strength and toughness of the new material, is of interest, particularly in reducing transport costs



By courtesy of Sheepbridge Stokes Centrifugal Castings Co. Ltd.

Fig. 6.—Ni-Hard Concrete Mixer Trough Blades.

and breakage due to rough handling in the field. Alternatively, the new iron offers mechanical properties, which would enable increased pressure to be safely used.

Whilst the engineering applications of spheroidal graphite cast iron are only now becoming established, there is no doubt whatever that a new era of foundry practice has been initiated by the practical development of this new product.

The new type of spheroidal graphite cast iron may be developed, using a variety of treatment agents. So far the initial work has been carried out with a nickel-magnesium alloy, which has proved simple and effective. As a result, the treated iron is alloyed generally with about 1% to 2% of nickel. It must be emphasised, however, that the addition of nickel is only incidental and is not essential to the process for producing magnesium treated irons, and other methods of adding magnesium are under review. Incidentally the Mond Nickel Company's Patents cover the addition of magnesium in any form to produce spheroidal graphite.

High Duty Cast Iron

Whilst pride of place has, as indicated, been given to spheroidal graphite cast iron in this review, it must not be overlooked that steady progress is being made in a number of other directions in the development of high duty and alloy cast irons. It is not long since the new British Standard Specification 1452 was published. In the meantime, steady progress has taken place in the routine production of castings to the higher grades of the specification.

Nickel-molybdenum combinations, giving refined structures, or the acicular type of iron, are used regularly for grades 23 and 26. Such irons have been widely adopted for cast crankshafts, camshafts, wheel hubs and other highly stressed components, especially for Diesel engines. These uses continue to extend.

Ni-Hard

Reference to modern technical literature fixes attention on the fact that rapid strides are being made in the adoption of Ni-Hard for wear resisting castings. Extensive service tests with Ni-Hard for grinding and milling equipment have been conducted, and notable success has been achieved in the mining industry with Ni-Hard to replace white cast iron on the one hand, and manganese steel on the other, as a result of its very high hardness and wear resistance. Similar success has

followed the adoption of Ni-Hard for cement mills, and from the data which have now been collected, covering long period of tests in service, it is now well established that Ni-Hard, at a price sometimes below and sometimes slightly above that of manganese steel, will frequently give from 50-100% increased life; thus showing substantial economies in plant operation.

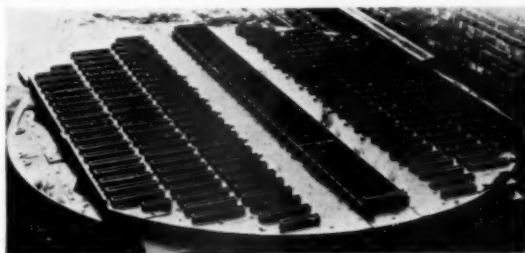
In other directions also the value of Ni-Hard as a wear-resistant iron is being increasingly appreciated. For example, successful tests have been described with it for plough points. In this connection, it offers substantial economy by giving several times the life of white cast iron, with a further saving in labour and fuel.

Austenitic Irons

The value of the austenitic cast irons to industry, as corrosion and heat-resisting materials, continues to be of interest. Special reference in this connection might be made to developments in petroleum refining. Under this heading, extensive schemes are in process of realisation, both at home and abroad, for the construction of large new refineries. These refineries, not only are designed for the refining of petroleum itself, but now generally combine establishments concerned with what have come to be called petro-chemicals. These include such products as soap substitutes and a variety of other industrial chemicals derived from petroleum and its by-products. The specialised equipment involved is called upon to resist chemical attack, frequently of a severe and peculiar nature. Cast iron enters largely into the construction of the equipment, and in this connection Ni-Resist, other types of austenitic cast iron, and the high-chromium irons are of outstanding value. Special sections of the plant also call for acid-resisting irons of the high-silicon type.

Another feature of interest is the increasing use of irons of special expansion characteristics, and particularly of the low expansion cast iron—Minovar, which is highly alloyed in order to produce castings comparable to the well-known "Invar." These low expansion castings are considered essential in some of the modern high precision machine tools, where accuracy of dimensions must be maintained under fluctuating temperature conditions.

On the technical side of cast iron development, reference must be made to the activity which has been current over the past two or three years in the Technical Committee of the Institute of British Foundrymen in



By courtesy of John Williams (Cardiff) Ltd.

Fig. 7.—Bubble Tray assembly in Ni-Resist for petroleum refining.

connection with internal stress in castings, and its various manifestations. Coupled with this is the question of stress relief. Recent papers, for example, at the Cheltenham Conference, have dealt with various aspects of this problem, whilst other papers published in recent times have dealt with the related subject of distortion in castings.

The above examples of progress in cast iron are perhaps sketchy and incomplete. First consideration has been given to the spheroidal graphite cast irons, which are now the topic of conversation among foundrymen throughout the world. Progress with these and with other types of high duty cast iron is, however, continuous, as the needs of modern engineering practice become ever more exacting.

Powder Metallurgy

Review of Progress during 1949

By R. A. Hetzig
Powder Metallurgy Limited

For the purpose of this review, the term powder metallurgy has been taken to include also the uses of metal powders in which they do not undergo a process of pressing and sintering. According to the textbooks, this is not strictly correct, but from a practical point of view it makes it possible to indicate some new and interesting developments in which metal powders play some part.

General Position

IT is apparent that powder metallurgy, as a technique for mass-producing small parts, is gradually settling down within its legitimate, but necessarily limited, sphere of usefulness. Even in America the exuberant optimism engendered by war-time outputs has given way to a distinctly sober appraisal of the situation, as Ziegfeld and Roll,¹ of the Metal Powder Association, New York, have shown in an article entitled "Powder Metallurgy—No Panacea." At the same time, these authors point out that the powder metallurgy technique is a genuine asset when it can be applied in circumstances in which competitive processes are inherently handicapped for one reason or another. The economic aspects of powder metallurgy have also been ably surveyed by Bonanno² who dealt not only with the prices of raw materials, where the absence of scrap with powders becomes increasingly important with diminishing size of the parts, but also with such questions as subcontracting, tooling, and the training of staff. In his view, considerable advantages accrue from having an integral powder metallurgy department in a works, provided it can be kept employed at a sufficiently high load factor.

Magnetic Applications

Among a number of suggestions for new powder metallurgy applications, Bonanno pointed out that a potential market of some 100,000 tons per annum existed for sintered flake iron powder if parts from such powder could be developed to replace laminated cores, etc., in the electrical and electronics industries. At this year's Exhibition of the Physical Society one of the large manufacturers³ in this country exhibited a series of E- and L- pieces made from flake-iron powder, the manufacture of which has now also been patented.⁴

Another development in the magnetic field is the magnetic fluid clutch. According to Saunderson,⁵ it appears that the problem of obtaining a suspension of carbonyl iron powder in a suitable oil by means of a suitable additive has been practically solved. When

the suspension is subjected to a magnetic field, the metal particles coagulate and decoagulate according to the strength of the field, and this effect can be translated into a corresponding frictional effect with the base plates. Several American companies have taken a keen interest in this development, but in the discussion of Saunderson's paper it was admitted by both the General Electric Co. and the Chrysler Corp. that they were still encountering considerable difficulties in getting a magnetic fluid clutch to operate satisfactorily. It will be interesting to see whether one or two industrial concerns in this country, who are reported also to be looking into this problem, are able to obtain any better results. The National Bureau of Standards, Washington, D.C., where this work originated, are now apparently testing these magnetic fluids on a laboratory scale for use as shock absorbers for automobiles or lorries, for the remote control of hydraulic systems, as a low-temperature casting material and as variable electrical resistors.⁶

Ferrocube materials have been developed by the Philips organisation, first at Eindhoven during the war and then later to some extent in the United States. They are really a magnetic ceramic material, but they may perhaps be included as they form an interesting competition for dust cores. They consist of mixtures of ferrites, each having the general formula $MO \cdot Fe_2O_3$, where M is a bivalent metal. Manganese-zinc ferrites and nickel-zinc ferrites have so far proved to have the most useful magnetic properties and besides the fact that the manufacture of these materials has been patented in several countries,⁷ considerable interest attaches to two papers that were presented at a Symposium of Papers on Ferromagnetic Materials, held recently by the Institution of Electrical Engineers. In one of these Polder⁸ dealt comprehensively with the changes in characteristics as a function of frequency and also with the explanation of these changes in terms of molecular structure. The practical side was presented by Latimer and MacDonald,⁹ of Mullard Electronic Products, Ltd.,

who described a number of high-frequency transformers and filter coils that had been fitted with Ferroxcube parts. At the same Symposium the whole field of magnetic powders and core materials was surveyed in a joint paper by Richards, Buckley, Bardell and Lynch.¹⁰

The Radio Corporation of America is reported to have a daily output of 5,000 iron powder core assemblies for their television sets.¹¹ Each assembly weighs some 20 oz., and the cost is given as 55-60 cents, compared with \$3.50 for laminated cores.

Sintered silicon iron containing 6-50% Si was investigated by Glaser¹² who found that by a suitable choice of hot-pressing and heat-treatment conditions properties identical to those of cast silicon iron could be obtained. A Patent of the American Electro Metal Corporation¹³ may be quoted in this connection according to which a deoxidising agent such as graphite, excess silicon or ferrosilicon containing carbon should be included in the iron-silicon mix.

Gas-Turbine Blades

The contribution of powder metallurgy to gas-turbine alloy manufacture is still potential rather than actual. The requirements of high resistance to creep and oxidation at elevated temperatures appear to be satisfactorily met by suitable thermal and mechanical treatments of cast alloys, as the number of jet planes in operation amply testifies. Jet engine manufacturers, in this country at least, have so far not concerned themselves to any serious extent with the properties of sintered materials for gas turbine parts, and they may continue to rely for the present on precision investment casting and the various machining methods. In the United States, however, two official reports from Government bodies have appeared which indicate that powder metallurgy is being considered as a possible alternative. Blackburn, Shevlin and Lowers¹⁴ have described the manufacture and properties of cermets—i.e., mixtures of ceramics and metal powders. Combinations of alumina with nickel, cobalt, iron, chromium and chromium-boron were tested, whilst nickel-magnesia, cobalt-magnesia and titanium-alumina were quoted as possibles by reason of their mutual solubilities. The second report, by Hoffman, Ault and Gangler,¹⁵ dealt with 80/20 titanium carbide-cobalt blades. Three such blades were tested in an experimental gas turbine together with 139 Vitallium blades. Under the set conditions the "ceramal" blades failed for different reasons, whilst in the same period only four out of 12 Vitallium check blades remained intact. Many more results are wanted before a definite opinion can be formed of these compound materials, but in theory such combinations should come fairly close to an optimum all-round resistance to thermal shock, creep and oxidation. The manufacturing procedures are not excessively difficult, and are perhaps less exacting than existing methods. A summary of all data published so far on ceramics and ceramals as turbine blade materials has been made by Bobrowsky.¹⁶

Apart from a British Patent of the General Electric Co., Ltd.,¹⁷ in which internal ducting in sintered gas turbine blades is obtained by diffusion or evaporation of pieces of wire inserted in the powder charge before compaction, the American Electro Metal Corporation has been active in this field. They have gone on record with sintered molybdenum or tungsten blades that are coated with chromium, aluminium or titanium,¹⁸ and

they have also described the manufacture of sintered iron-graphite blades that are first impregnated with a molten copper alloy and then coated with tin, zinc or aluminium.¹⁹ A Patent of the Westinghouse Electric Corporation²⁰ may also be relevant in this connection. Molybdenum-chromium or tungsten-chromium alloy powders are made by heating chromium oxide and molybdenum carbide or any equivalent mixture in which the oxygen and carbon can come off as carbon monoxide.

High Melting-point Metals

Platinum, tungsten, tantalum, osmium, etc., are the classical examples of powder metallurgy in which the sintering technique conducted at temperatures considerably below the melting points of the respective metals was, and largely still is, indispensable. After 40 years one would hardly expect to find tungsten filaments mentioned in a progress report on powder metallurgy, but even to-day they are still manufactured everywhere under conditions of complete secrecy. This applies especially to the doping of the tungsten oxide prior to reduction of the latter to the metal powder. An interesting paper on one current method of manufacturing tungsten powder from ore (scheelite) was presented by Smeaton²¹ at a Symposium on the Refining of Non-Ferrous Metals, held by the Institution of Mining and Metallurgy.

Another paper at this Symposium, by Miller,²² dealt with the production of zirconium powder for which two competitive processes are available. One employs the decomposition of zirconium tetra-iodide on a hot filament, whilst in the other a powder is obtained by reducing zirconium tetrachloride with magnesium in the vapour phase. The latter process is known as the Kroll process, and full details of it have been given in a recent Patent.²³ Zirconium is important as a getter in valve manufacture, but is not otherwise used to any large extent.

Platinum is made nowadays both by casting and from powders. One of its many uses is as sparking plug electrodes for aero-engines, and since for this purpose the metal behaves differently according to its method of manufacture, a comparative investigation of the physical properties of the two qualities of platinum was made by Middleton, Pfeil and Rhodes.²⁴ They concluded that in the sintered wire the fibrous structure was retained well above the recrystallisation temperature of the cast wire, presumably owing to the presence of suitably dispersed porosity, and that for this reason sintered platinum gave better results when used in the application mentioned above.

At one period during the last 18 months titanium almost acquired notoriety, especially in the American technical press, and a most useful purpose was served when the U.S. Office of Naval Research sponsored a Symposium on Titanium in December, 1948. Seventeen papers were presented, dealing as fully as circumstances permitted with the whole field of production of the metal, its properties, some of its alloys and some of its possible applications.²⁵ The manufacture of ductile titanium from Australian rutile was also described by Worner.²⁶ Much will undoubtedly be heard of titanium one day, but it is only too easy to underestimate the amount of work that will have to be undertaken if titanium and its alloys are to play a major part in the metallurgical industry.

A good paper on molybdenum has been forthcoming from Miller.²⁷ Here again interest is stimulated by the fact that the metal can be produced by two competitive processes. In the Westinghouse process pressings of molybdenum powder are sintered successfully by using an atmosphere of moist hydrogen, whilst in the Climax Molybdenum process, a continuous rod of pressed powder is melted in an electric arc and then cast in water-cooled copper moulds. One application that may possibly absorb large quantities of the metal is the lining of gun barrels.²⁸

Hard Metal

Carbide tools may soon fall into the same category as tungsten filaments so far as their powder metallurgy origin is concerned. Although their price is higher than that of high-speed steel, they possess a markedly longer life and give, in many instances, a superior performance. An important paper on the use of carbide cutting tools was presented by Eatough and Eckersley.²⁹ Some interesting details on the manufacture of carbide dies were published by the Allegheny Ludlum Steel Corporation,³⁰ and "Materials and Methods" devoted one of their Manuals (No. 46) to the subject.³¹ In this country a small brochure on "Cemented Carbide Tools" was published with Shute³² as author, whilst Sandford³³ contributed an excellent article describing the control of the properties of hard metals in the manufacturing stage.

Particle size measurement is important in hard metal manufacture. Burden and Barker³⁴ presented a very interesting paper on the subject, though in the discussion opinion was not completely unanimous as to the value of the Spekker and turbidimeter methods. Morley³⁵ contributed some further data on the size and shape of tungsten particles, obtained by means of the electron microscope, whilst Delisle and Davis³⁶ discovered sub-grain structures in tungsten powders, also by means of the electron microscope.

Diamond Tools

Vitreous materials, plastics and powdered metals are used for bonding diamond tools for different purposes. The metal bond usually consists of brass, bronze or iron, and the alloys that have been tried at different times are legion. An interesting addition is an iron boride bond developed by the Norton Co.,³⁷ that is prepared from a powdered mixture of electrolytic iron and boron carbide. From a production point of view it is claimed by J. K. Smit & Sons³⁸ that ceramic moulds impressed by a master tool are superior to graphite moulds. In both cases, the diamonds are embedded in metal powder for consolidation by hot-pressing.

Miscellaneous Applications

Diamonds or hard metal can be brazed to steel either with zirconium (hydride)-silver³⁹ or with titanium hydride-copper.⁴⁰ Another method of brazing carbide tool tips to steel is to use a copper strip coated on both sides with silver solder.⁴¹ A series of useful solder pastes has been announced in the States,⁴² and a putty-like material consisting of aluminium powder and vinyl resin is said to be selling in quantities of 300,000 gal. per month for repairing damaged automobile body parts.⁴³ The U.S. Radium Corporation has recently patented the use of metal powders for obtaining radioactive

materials in which the radioactive constituent is uniformly distributed.⁴⁴

Theories of Pressing and Sintering

Wulff⁴⁵ has reported some investigations on the distribution of pressure on the outside of a cylindrical die. It is shown fairly conclusively that laminar cracks in pressings may be formed by elastic deformation of the die when the compacting pressure is released and the tension of the die wall relaxes against the compacted powder. Dilatometric measurements were used for studying the sintering process by Silbereisen⁴⁶ in Germany and by Duwez and Martens⁴⁷ in America, whilst a Symposium on the Physics of Powder Metallurgy held by Sylvania Electric Products Inc. has been ably reviewed by Lenel.⁴⁸ The full text of these papers will not be available for some months.

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One book has appeared during the year—namely, Volume I of Goetzels⁴⁹ "Treatise on Powder Metallurgy." It may be recommended for its contents from every point of view, but is fairly expensive at a price of £6 since the devaluation of the pound. Finally, reference may also be made to the "Metal Powder Report,"⁵⁰ from which the material for this review has been largely drawn.

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Some Recent Developments in Magnesium Alloys

By R. G. Wilkinson, B.Sc.

Deputy Chief Metallurgist, Magnesium Elektron, Ltd.

Considerable progress has been achieved in the magnesium alloy field, but in this review particular attention is directed to three outstanding developments; alloys based on the magnesium-lithium system; the zirconium-containing casting alloys; and magnesium-alloy anodes for the galvanic protection of iron and steel.

THREE recent developments in the magnesium-alloy field will be considered in this review. The first concerns alloys based upon the magnesium-lithium system and lies wholly in the sphere of long-term research since, although present results show great promise of cold-workable high-strength alloys of even lower density than pure magnesium, there are a number of formidable difficulties yet to be overcome. The second has already reached its main objective, namely, the production development and high-duty application of the Zr-containing casting alloys in respect of which almost three years of foundry and service experience is available. The third matter to be considered is the use of magnesium-alloy anodes for the galvanic protection of iron and steel, notably pipelines: few metallurgical problems are involved in this application, but it is worthy of attention in view of its increasing importance.

Lithium-containing Wrought Alloys

The magnesium-lithium system was first investigated by a number of workers^{1, 2, 3, 4} in the early nineteen-thirties and the equilibrium diagram established by Grube, von Zeppelin and Bumm¹ (see Fig. 1) has since been found to be substantially correct. The first record⁵ of lithium being tried as a useful alloying addition to magnesium alloys refers to pre-war research by the I.G. Farbenindustrie, but the results are not stated. In more recent years the subject has attracted, and continues to command, much attention both in the U.K. and the U.S.A. To the present writer's knowledge, however, and apart from patents,^{6, 7, 8, 9} only two important publications have so far appeared. Hume Rothery, Raynor and Butchers¹⁰ have described their work on the alpha solidus and alpha solid solubility curves of the binary system (in which they substantially confirmed the findings of Grube et al¹ and Hofmann⁴) and on certain aspects of the ternary alloys with silver. This third element had been chosen from theoretical

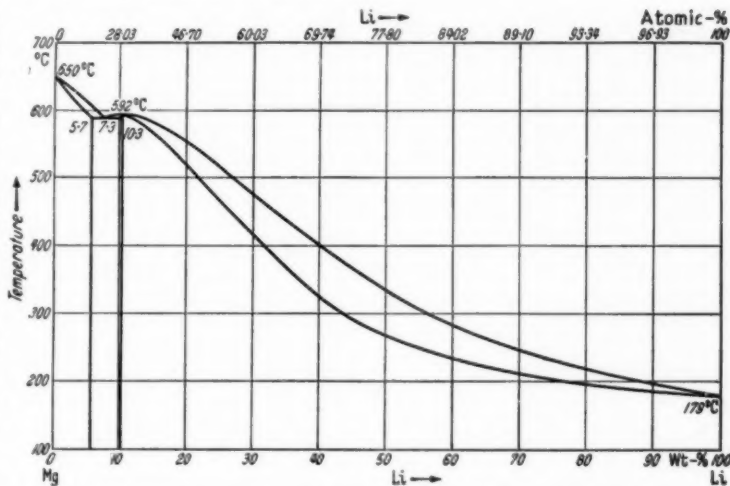


Fig. 1.—Magnesium-lithium equilibrium diagram (Grube).

considerations as being likely to yield a useful precipitation hardening alloy and the results gave favourable general indications, although no specific hardness or mechanical property determinations were reported. In a discussion at the end of the paper, predictions were also made regarding other probable hardening elements worthy of investigation, namely, copper, zinc and aluminium. Hume Rothery's selection of silver for addition to the magnesium-lithium base, and the general accuracy of his other suggestions, have now been confirmed in a most informative paper by Jackson, Frost, Loonam, Eastwood and Lorig¹¹ in which are reported the results of a systematic and comprehensive research project carried out at the Battelle Memorial Institute. The main findings of this work (in which all tests were made on wrought material) will now be summarised:—

1. Binary alloys with up to about 5.7% lithium (see Fig. 1) are of the single alpha phase type and possess the close packed hexagonal crystal lattice structure of magnesium. With more than about 10.3% lithium they are wholly beta phase and, like lithium, have a body centred cubic lattice. Intermediate compositions are alpha-beta alloys.
2. As would be expected, the binary beta alloys are much more ductile and cold workable than pure magnesium, whilst their proof stresses are lower. For example, the 13% lithium alloy has an elongation of over 40% with a yield strength (0.2% proof

¹ Grube, G., Zeppelin, H. von and Bumm, H., *Z. Elektrochem.*, 1934, **40**, 160-4.

² Henry, O. H. and Cordiano, H. V., *Trans. Amer. Inst. Min. Met. Eng. (Inst. Metals Div.)*, 1934, **111**, 319-32.

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⁶ U.S.P. No. 2,317,980.

⁷ U.S.P. No. 2,376,868.

⁸ B.P. No. 612,924 (corresponding to U.S.P. No. 2,453,444, which lists further pending applications).

⁹ B.P. No. 624,861.

¹⁰ Hume-Rothery, W., Raynor, G. V. and Butchers, E., *J. Inst. Metals*, Vol. 71, Part 2, Dec., 1945, 589-601.

¹¹ Jackson, J. H., Frost, P. D., Loonam, A. C., Eastwood, L. W. and Lorig, C. H., *Journal of Metals*, 1949, **2**, (1), 149-68.

stress) of only about 5 tons/sq. in., and can be cold rolled with extremely heavy reductions. Hot-working characteristics are very good. Although the body centred cubic beta phase does not exist at lithium contents lower than about 5.7%, even the 2% alloy shows improved ductility and cold-working behaviour.

3. The beta alloys possess other advantages over conventional magnesium-base materials in that their elastic modulus (approx. 6.5×10^6 lb./sq. in.) and proof stresses in compression equal or surpass those in tension.
4. The binary alloys may be strengthened by additions of other elements, notably silver, cadmium, aluminium and zinc, alone or in combination, and such compositions are of the precipitation-hardening type.
5. The magnesium-lithium base ternary, quaternary and quinary alloys can be solution treated and have attractive mechanical properties in the extruded and aged condition, and (with lithium in excess of about 10.3%) retain the advantages associated with the body centred cubic lattice structure. However, these otherwise attractive alloys possess three unfortunate characteristics of a serious nature: they have only limited work-hardening capacity, their mechanical properties in the age-hardened state are unstable at temperatures as low as 65°C. and their corrosion resistance is poor.
6. It appears that those alloying additions which help most in improving work-hardening characteristics also have a beneficial action in increasing stability, and silver is particularly effective in this respect. The composition reported as being one of the best (though not sufficiently better to be acceptable) from all points of view except that of corrosion contains 11.5% lithium, 15% cadmium and 5% silver. After extrusion and ageing for 24 hours at 65°C., typical mechanical properties of 19 tons/sq. in. 0.2% proof stress, 20.5 tons/sq. in. ultimate stress and 8% elongation are obtainable, and are stable over an extended period.
7. Whereas the corrosion resistance of the complex alloys is poor, the beta binary appears to compare well with normal commercial magnesium-base alloys in this respect and may be used for cladding the stronger materials.

8. The specific gravity of the beta binary alloy with 11.5% lithium is about 1.4, but when strengthening additions of other elements are made it lies between 1.45 and 1.65. However, this range presents advantage over the value of 1.8 for normal magnesium-base alloys and the new materials also compare favourably on a strength-weight basis with the strongest commercial aluminium-base alloys. Consequent upon their low density, the lithium-containing alloys show particular superiority over other materials in resistance to buckling under compression.
9. The alloys can be melted without difficulty in steel crucibles under an argon atmosphere or a lithium chloride-lithium fluoride flux, or a combination of both, and can be poured in air under the protection of the oxide skin around the stream.

The foregoing will have given some indication of the serious outstanding problems as well as of the considerable promise disclosed in the investigation of the magnesium-lithium base alloys. To the difficulties of low work-hardening capacity, instability and poor corrosion resistance must be added the disadvantage of the very high cost of the pure lithium of low sodium content required, at present around £9 per pound for a hardener alloy containing 60% lithium. In view of these factors, it may be that the work-hardening and relatively stable alpha hexagonal alloys containing only sufficient lithium to improve cold-working behaviour and other properties will be developed to a commercial stage before the more potentially promising beta compositions. Undoubtedly the alpha-beta alloys will also be thoroughly explored.

Zirconium-containing Casting Alloys

It has been said that the second project has already reached its main objective. The difficulties met and overcome in years of chemical and metallurgical research at Magnesium Elektron, Ltd. on the alloying of zirconium with magnesium have been outlined by Ball;¹² and Emley¹⁴ has recently published a more detailed account of some of these difficulties, solution of which finally led early in 1947 to the availability for commercial production and at reasonable cost, of alloying ingredients giving castings of good quality, high mechanical properties and

- ¹² Ball, C. J. P., *Metallurgy*, Vol. 35, Nos. 206-7, Jan. and Feb., 1947.
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TABLE I.—NOMINAL COMPOSITIONS AND TYPICAL TENSILE PROPERTIES OF THE ELEKTRON CASTING ALLOYS

Alloy and Condition	D.T.D.† Specn.	B.S. Specn.	Alloying Additions, %					Tensile Properties (D.T.D. Sand Cast Bars)†		
			Zr	Zn	RE‡	Al	Mn	0.1% P.S. Tons/sq. in.	U.T.S. Tons/sq. in.	Elongation % on 2 in.
Zirconium-containing alloys :										
Elektron Z55										
As cast	Draft 711	—	0.7	4.5	—	—	—	7.0- 8.5	13.0-17.0	7-15
Heat treated	Draft 721	—	—	—	—	—	—	8.5-10.5	15.0-18.0	5-12
Elektron ZRE1										
As cast and annealed	In Draft	—	0.65	2.5	2.5	—	—	5.0- 6.0	9.0-11.0*	3-6
Elektron MCZ										
As cast and annealed	In Draft	—	0.65	—	3.0	—	—	5.0- 6.0	9.0-10.5*	3-6
Aluminium- and zinc-containing alloys :										
Elektron AS										
As cast	59B	1277	—	0.4	—	8.0	0.3	4.5- 5.5	9.0-11.0	2-5
Solution treated	289A	1278	—	—	—	—	—	4.5- 5.5	13.0-17.0	6-15
Elektron AZ91										
As cast	136B	1273	—	0.4	—	9.5	0.3	4.5- 6.0	8.0-10.5	2-4
Solution treated	281A	1274	—	—	—	—	—	5.0- 6.0	13.0-16.0	4-8
Fully heat treated	285A	1275	—	—	—	—	—	6.5- 8.6	13.0-16.5	1-4

† All the lower tensile property figures in the ranges for the zirconium-containing alloys are draft D.T.D. specification minima. For the aluminium- and zinc-bearing alloys, the lower figures for U.T.S. and Elongation % are D.T.D. (and B.S.) minima; there is, however, one exception to this in that D.T.D. 136B does not call for a mandatory elongation value.

* U.T.S. values at 150° and 200°C. are 9.0-10.0 and 8.5-9.5 tons/sq. in., respectively.

‡ Rare-earth metal.



By courtesy of Blackburn and General Aircraft Ltd. and the Dunlop Rubber Co. Casting by Sterling Metals, Ltd.

Fig. 2.—Development wheel in Elektron magnesium-zirconium-zinc alloy, designed for a large transport aircraft with a take-off weight of 95,000 lb.

complete freedom from the flux inclusions which had been so prevalent in the early stages of the investigation. More recently, Ball¹⁵ has included later advances in regard to the zirconium-containing alloys in a paper presented at the Fourth Empire Mining and Metallurgical Congress, and Sully¹⁶ has also made mention of the alloys in a general article.

Elektron Z5Z.—This is a high proof-stress alloy containing about 0.7% zirconium and 4.5% zinc, and although it is used primarily as a heavy duty structural alloy at normal temperature, it is also serviceable up to about 150° C. It has the very fine grain size associated with the zirconium addition (obtained without superheating) and, as will be seen from Table I, its properties are substantially in advance of the long-established aluminium- and zinc-containing alloys. The high proof stress has already been noted, but it may be mentioned in addition that, for the first time, mandatory proof minima are proposed for inclusion in the D.T.D. specifications, for both the "as cast" and heat-treated

¹⁵ Ball, C. J. P., Paper No. H.I. 11, presented at the Fourth Empire Mining and Metallurgical Congress, July, 1949.

TABLE II.—WÖHLER FATIGUE STRENGTHS OF THE ELEKTRON CASTING ALLOYS

Alloy and Condition	Fatigue Endurance Value (50 × 10 ⁶ Reversals)	
	Tons/sq. in. Unnotched	Tons/sq. in. Notched*
Zirconium-containing alloys:		
Elektron Z5Z		
As cast	5.25	4.25
Heat treated	5.5	5.5
Elektron ZRE 1		
As cast and annealed	4.5	3.75
Elektron MCZ		
As cast and annealed	4.2	3.5
Aluminium- and zinc-containing alloys:		
Elektron A8		
As cast	5.5	4.0
Solution treated	5.75	4.5
Elektron AZ91		
As cast	5.5	4.25
Solution treated	6.0	5.0
Fully heat treated	4.75	4.0

* Semi-circular notch with a depth of 0.047 in. giving a calculated stress concentration factor of approximately 2.

alloys, now in advanced draft form. The absence of notch sensitivity in fatigue after the standard low-temperature heat treatment is also worthy of emphasis (see Table II).

In the foundry, three years production experience has confirmed that Z5Z is much less prone to microporosity than the older alloys and tensile tests of sectioned castings have shown that not only is there better conformity with separately cast test bar values, but there is also less scatter of properties throughout the casting. An important advantage to the foundrymen (associated with the reduction of microporosity), is that a difficult casting can be produced with a curtailed period of foundry development.

Z5Z castings are now in established use, particularly in the aircraft industry where soundness and enhanced properties are at a premium. The alloy is showing strong signs of superseding A8 for landing wheels and indeed it has been reported that the great majority of the aircraft at the last S.B.A.C. Exhibition were fitted with wheels made in the new material. An example of a large wheel cast in Z5Z for a prototype aircraft is shown in Fig. 2. Topical mention may also be made of the fact that the new De Havilland Comet jet-engined passenger aircraft carries many Z5Z castings in the airframe.

Elektron ZRE 1 and MCZ.—These zirconium- and rare earth metals-containing alloys are specifically suited for service at elevated temperatures up to 200° C. (and higher), under which conditions they possess excellent creep properties. As illustrated in Fig. 3 for ZRE 1, creep resistance is much superior to that of the older alloy A8 and in fact both the new alloys are equivalent to the aluminium-base RR50. Combined with this essential characteristic which is conducted by the rare earth metals addition, the alloys have relatively high thermal conductivity and good tensile properties at normal temperatures which result from the zirconium content. Also, as will be seen from Table I, the ultimate stress falls off but little with increasing temperature up to 200° C. In connection with the mechanism by which rare earth metals additions lead to improved creep properties, reference should be made to valuable work at the N.P.L. by Mellor and Ridley.¹⁷

It may be recalled that MCZ, containing 0.6-0.7%

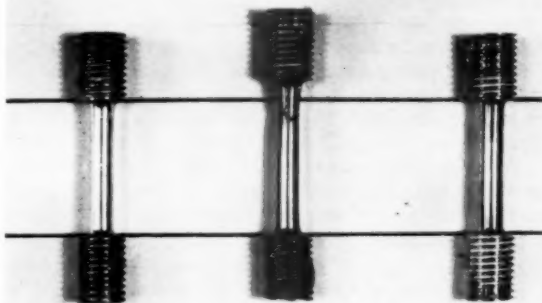
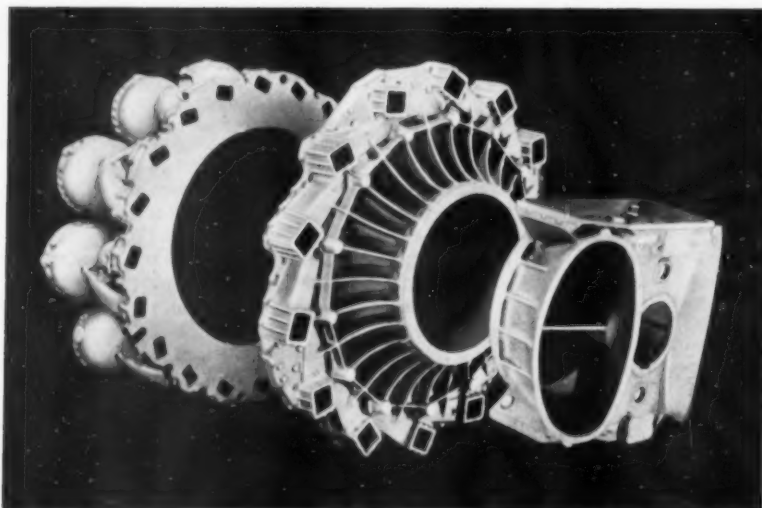


Fig. 3.—Specimens which have each been loaded for over 1,000 hrs. at 2 tons/sq. in. at 200° C. The RR.50 and ZRE 1 specimens have extended less than 0.000001 in./in./hr. The Elektron A8 specimen has broken after extending about 20%.



By courtesy of the De Havilland Aircraft Co. Castings by Sterling Metals, Ltd.

Fig. 4.—Elektron castings in magnesium-zirconium-zinc rare-earth metals alloy for the De Havilland "Ghost" jet-propulsion unit.

zirconium and 3% rare earth metals, was introduced late in 1946 following development by Murphy and Payne¹⁸ and M.E.L., commercial production commencing early in the following year. This alloy continues in production but ZRE 1, containing 0.6–0.7% zirconium, 2.5% rare earth metals and 2.5% zinc, is now to be preferred for many purposes, mainly in view of its better foundry behaviour and slightly improved tensile properties at normal temperature. Both alloys are completely free from microporosity and are correspondingly pressure-tight: a casting in ZRE 1 has been paraffin tested at a pressure as high as 2,500 lb./sq. in. without leakage. ZRE 1 and MCZ are covered by one D.T.D. specification which is still in draft.

The alloys are now in extensive use in jet-propulsion units and it may be remarked that it was fortunate that the availability of these improved materials coincided with the designers' more stringent requirements associated with the development of engines of higher thrust. A typical example of their successful application is illustrated in Fig. 4: this is another case of the De Havilland Comet carrying zirconium-containing alloys, since Ghost jet units are fitted to this prototype aircraft which has already made such remarkable test flights.

In the foregoing an attempt has been made to give an objective account of the principal characteristics of the zirconium-casting alloys. No apology need be offered if its terms appear somewhat eulogistic, since results are amply proving that the commercial introduction of these new materials does indeed constitute an important advance, and this receives additional confirmation from the fact that they are now being manufactured under license in the U.S.A., Canada and several European countries, notably Sweden, Switzerland and Holland.

Magnesium-Alloy Anodes for Galvanic Protection

The principle of galvanic protection against corrosion or, as it is often termed, sacrificial protection, will be well known to all metallurgists and needs no repetition here. It may be recalled that this method was first proposed and used by Sir Humphrey Davy in collabora-

tion with Michael Faraday in about 1825, and considerable success attended their experiments on the application of zinc and iron anodes to the protection of the copper sheeting of wooden warships. Since those early times galvanic protection has been used quite widely in many fields, and for iron and steel pipelines or other buried structures protective current has sometimes been applied either directly from generators or transformers, or has been produced by zinc anodes. It is, in fact, only in the last few years that the use of magnesium-alloy anodes has been found to offer certain definite advantages, and it may be of interest to summarise the underlying reasons which Higgins¹⁹ has detailed in a comprehensive article.

There are four main requirements to be satisfied in the choice of anode material for the protection

of iron and steel, and these will be considered as follows:—

1. The potential difference between the anode and the iron must be as high as possible to provide maximum driving force for the protective current passing through the ground. Considering the normal electrode potentials of the common metals referred to the standard hydrogen electrode, only four metals have potentials more negative than iron and are thus available for use as protective anodes. These are chromium — 0.56 v., zinc — 0.76 v., aluminium — 1.33 v. and magnesium — 1.55 v., and are to be compared with iron at — 0.44 v. It will be seen that the potential difference between zinc and iron is only 0.32 v. as against the 1.11 v. between magnesium and iron. A further point to the advantage of magnesium in this connection is that, unlike zinc or aluminium, its potential difference against iron happens to be substantially independent of the pH value of the electrolyte—usually the soil.
2. For the most economical use the anode material should possess a high electrochemical equivalent. Here again magnesium scores over zinc since the values are 1,000 and 372 ampere hours per pound, respectively. The figure for aluminium is 1,352 ampere hours per pound.
3. The anode must be as free as possible from polarisation tendencies in the ground, and must not form protective films; either of these factors will, of course, reduce the current flow and so interfere with protection. Magnesium is almost wholly exempt from polarisation or film formation in the ground, whereas aluminium and zinc (which will have been noted to rival magnesium in regard to electrochemical equivalent and/or potential difference) exhibit these unfavourable characteristics.
4. For long life and economy, the anode should not be liable to excessive "general" corrosion in the ground leading to metal wastage without generation of useful current. And a second related point is that

¹⁸ Murphy, A. J. and Payne, R. J. M., *J. Inst. Metals*, Vol. 73, Part 3, Nov., 1946, 105–27.

¹⁹ Higgins, W. F., *Civil Engineering*, Vol. 44, No. 522, Dec., 1949 and Vol. 45, No. 523, Jan., 1950.

dissolution of the anode should be reasonably uniform to prevent local disintegration and possible loss from the circuit of portions of the anode. The first of these requirements has been met by careful control of impurities in the magnesium alloy used, with consequent reduction in the numbers of cathodic particles giving rise to "general" corrosion in which local galvanic action in the sacrificial anode consumes metal without contributing current to the protective circuit. Uniform dissolution is ensured by correct choice of alloying additions to the magnesium.

From the foregoing consideration of the main essentials, it will have been seen that magnesium alloys are especially suitable for the protection of iron and steel. There is, however, one other important point in their favour, and this is concerned with inhibition of the bacterial corrosion of iron under anaerobic conditions which may exist in heavy water-logged clay soils. The bacteria concerned can thrive only under pH conditions in the range 5.5-9.0, and it appears that magnesium anodes may afford protection against this type of attack by reason of the deposition of magnesium hydroxide around the iron at about pH 10.

The standard type of magnesium alloy anode which is finding increasing use in the U.K. for the protection of cast-iron water mains, and overseas for oil pipe lines, is shown on the left in Fig. 5. In this country the anodes are usually installed on the smaller sizes of pipe with a spacing of about six to the mile, and under these conditions they can be expected to have a useful life of 5-10 years, during which adequate protection of those parts of the metal which have become exposed will be maintained. On the right of Fig. 5 is shown the "bagged" anode complete with "back-fill" which is called for in certain special instances. Other types of anode are being applied for the protection of mooring buoys and seawater structures such as piers. There also appears to be a promising field of use for small anodes in domestic galvanised iron hot-water tanks and cisterns.

Naturally it will be some years before a final evaluation

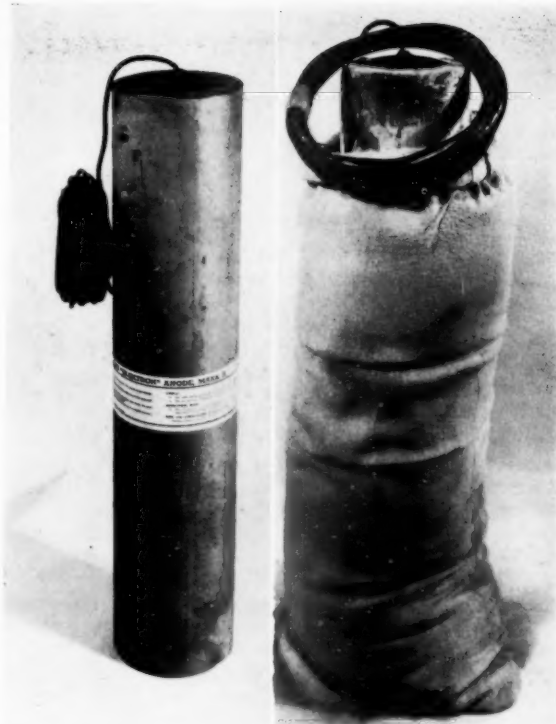


Fig. 5.—Standard Elektron Mark II anode (on left) and "bagged" anode with back-fill (on right).

of the utility of protection by magnesium alloy anodes can be made. Results to date are, however, extremely promising, and the method may eventually result in the saving of a substantial part of the very considerable expenditure involved in the re-laying of leaky pipes.

Correspondence

Recovery of By-Product Metals in the Smelting of Copper Alloy Scrap

In the account of the works practice of the Zinnwerke Wilhelmsburg G.m.b.H., in the review by Miss Whitaker on the above subject published in our October issue, and referred to on p. 296, it was stated that two B.I.O.S. reports gave accounts that differed in detail, particularly in regard to the treatment of slags and drosses at this works. The following explanatory letter has been received from a member of the team responsible for one of the B.I.O.S. reports.—EDITOR.

The Editor,

Dear Sir,

As a member of the team responsible for B.I.O.S. Report No. 1220, I feel that some explanation is necessary concerning the analysis and treatment of the slags from the blast furnace shown in the flow sheet, Fig. 1. It ought to be explained in the first place that the terms of reference of the team were not identical to those for the earlier team responsible for Report No. 25, published some twelve months earlier. The flow sheets reproduced in Miss Whitaker's article represent the total picture,

which was indeed a most complicated affair, and no attempt was made to itemise the various processes, which the earlier team had most thoroughly indicated.

As already suggested, the treatment of the slags from the blast furnace in this particular case depended on the analysis, which in turn appeared to be varied according to the type of charge made to the blast furnace. While the analysis of the slag shown in Report No. 25 may have been the more usual type from this blast furnace, we found slags running as high as 10 and 12% of tin. This type was shown in Report No. 1220 as we could find no mention in any earlier report.

The Report was made to present the picture over here as it appeared to the team. All criticism was withheld, as it should be, but it may be opportune to mention here that, so far as the treatment of slags and drosses generally from the various units was concerned, the time and trouble involved in the recovery of the metals therefrom, under pre-war British conditions at any rate, would have proved most uneconomical.

May I take this opportunity of thanking the British Non-Ferrous Metals Research Association and Miss Whitaker for a most interesting review?

(Signed) W. G. MOCHRIE.

Tyseley Metal Works, Ltd.,
Birmingham, 11.

Copper and Copper Alloys

Technical Progress in 1949

By E. Voce, Ph.D., M.Sc., F.I.M.

Copper Development Association

Copper was one of the first metals to be employed by man and it has since played an important part in almost every phase of his activities; its applications are ever widening and it is claimed that, during the last two centuries, world production of copper has increased a hundred fold. But each year witnesses further progress and in this review the author singles out particular aspects of development from a wide field of achievement.

FROM an industrial point of view the year appears to have passed somewhat uneventfully, except for devaluation; the full effects of which have not yet become clear. During the spring and summer, prior to devaluation, there had been several downward movements in the price of raw copper, but since then the price has risen to a value higher than that which ruled at the beginning of the year. Fabricators of copper and its alloys are still working at more or less full capacity, though wartime arrears of orders seem now to have been cleared, and deliveries have consequently become easier.

An outstanding technological event was the holding of the Fourth International Mining and Metallurgical Congress, with a concurrent Symposium on the Refining of Non-Ferrous Metals, in this country during the summer. Contributions relevant to copper were presented at both these conferences, and are described in their appropriate places in the notes which follow.

The Production of Copper

Prospecting and Ore Reserves.—A subsidiary of the Anaconda Copper Mining Co. is preparing to start active development of the great sulphide orebody at Chuquibambilla, which is claimed to be the largest in the world.¹ The growth of the Anaconda Copper Mining Co. itself has been traced by Newlin² from the organisation of the Butte district for placer-gold operation in 1866 up to the present, including a description of the recently formulated Greater Butte Project, while a useful picture of America's reserves of copper ore and production has appeared in a series of articles by Goss and Honeyman.³

In British Columbia the Copper Island Property in Babine Lake is to be extensively explored.⁴ Diamond drillings in the late 1920's indicated the existence of about 8,000,000 tons of ore assaying 0.8% of copper, with small amounts of precious metals. Also within the Empire, an account of the development of copper production at Mount Lyell, Australia, has been published by Salamy.⁵ At home there is some talk of reopening the copper mines at Amlwch in Anglesea if a scheme under consideration for the industrial development of the area goes forward,⁶ though it is unlikely that the scale of operations could be sufficient appreciably to augment our supplies of copper.

The mining and metallurgical industries of Sweden have recently been the subject of an extensive review.⁷ The principal mines now being worked for copper are those at Suxerget, Garpenberg, Boliden, Kristineberg and Adak. The output in recent years has been between 50,000 and 60,000 tons per annum, from which about

16,000 tons per annum of blister and refined copper have been produced in the country, mainly at Ronnskar on the Baltic Sea, where orthodox practice is followed. The ores are complex, and special methods of flotation have been developed.

Since Finland was deprived of the nickel mines and smelting plant at Petsamo, her most important reserves of non-ferrous metals are the copper ore deposits at Outokumpu.⁸ It is, in fact, the largest known deposit of copper ore in Europe. The ore carries from 3.5 to 4% of copper, and is separated by flotation into three different kinds of concentrates, rich respectively in copper, sulphur and zinc. The copper concentrates are smelted at Harjavalta and electrolytically refined at Pori, while the sulphur concentrates are used for making sulphuric acid and sulphite cellulose. The capacity of the copper refinery at Pori is about 24,000 tons per annum. Other copper mines in Finland include those at Nivala, Ylöjärvi, Orijärvi, Haveri and Aijala.⁹ Their output is small compared with that of Outokumpu, but other metals such as nickel, lead, silver, zinc and gold are also derived from certain of them.

Turning southwards, Lorenz¹⁰ has reviewed the undeveloped mineral reserves of the Turkish Republic, and reports that a great number of copper ore deposits have been found, though few of them have been opened. Up to the present the most important discovery is that at Ergani-Maden. Copper mining in Cyprus has been resumed since the end of the war¹¹ and an ore reserve of over a million tons of gold-copper-silver pyrite, amenable to low cost open-cast working, has been proved.¹²

Copper mining and milling has been resumed in the Philippines, and projected plans for the industrialisation of the islands include a copper smelter, two copper mills four non-ferrous foundries, a copper and brass extrusion and rolling plant and three plumbing goods factories.¹³

Smelting and Refining.—Signal recent events in connection with smelting and refining have been the Fourth Empire Mining and Metallurgical Congress already mentioned, and the concurrent Symposium on the Refining of Non-Ferrous Metals sponsored by the Institution of Mining and Metallurgy.

A point made by Cook¹⁴ in his survey of copper and its alloys presented to the Empire Congress was that while no single innovation in respect of plant, processes or materials had been revolutionary or had brought about any profound change in the industry, yet numerous important advances had contributed to its progress and well-being. The paper by Boggs¹⁵ on developments in the pyrometallurgy of copper, with special reference to

North American practice, is remarkable for the wealth of detailed information which has been packed into fifteen pages. It is difficult to single out major developments from among those which the author describes, but it is apparent that the building of larger reverberatory furnaces lined with magnesite, including the increasingly popular suspended magnesite roof, has done much to increase efficiency of production, while electric furnaces are gaining ground, especially for remelting cathode.

Other papers in the Congress which deal with copper production among other matters include those on the mineral resources of Australia,¹⁶ Canada^{17, 18} and South Africa^{19, 20}.

Concurrently with the Empire Congress, the Institution of Mining and Metallurgy held a symposium on the refining of non-ferrous metals, at which three important papers concerning copper were presented.

In the first of these, on fire refining, Miller²¹ quotes figures to show that the world production of copper has increased nearly a hundredfold since the early 1800's, and that about 90% of the total is treated by fire refining, the remaining 10% comprising cathode sold as such for the manufacture of alloys and cathode remelted under conditions which do not involve the characteristic fire refining cycle of oxidation, fluxing and poling. Only about one-sixth of all the copper that goes through a fire-refining process does so directly from the blister stage, for five-sixths of the whole is also electrolytically refined. The author describes in detail the various types of fire-refining process in current operation, with special reference to British practice, and concludes with an appraisal of Britain's present position and future outlook in this respect. He expresses the view that the future would appear to be more promising than might be expected from present conditions.

Reading the paper by Bauld²² on "Trends in Methods of Melting and Casting for High Conductivity Copper Wire Bars" brings the thought that the eventual demise of the conventional horizontally cast wire bar of tough pitch copper, with its irregular section and oxygen-enriched set surface, is foreshadowed. It is purely a matter of economics, and the onus is on the refiners to bring the premiums demanded for the vertically cast bar more closely into line with the fabricators' appreciation of its qualities. On the subject of continuous casting, the author suggests that, while both oxygen-free and phosphorus deoxidised copper are being produced commercially by this method, "the most rapid and widespread benefits would, of course, be realised if tough pitch copper could be continuously cast." It seems, however, reasonable to suggest that efforts would better be directed towards the development of a continuous casting technique for the oxygen-free variety. In the light of modern achievement, there would appear to be little reason for regarding the presence of cuprous oxide in copper as other than a permissible concession to cheap production.

A third paper in the symposium comprises a detailed description by Friggens, Page and Milligan²³ of the electrolytic refinery at Nkana, the main function of which is the removal of the troublesome element bismuth. The plant operates on orthodox lines and the cathodes are remelted and poured into wire bars from a reverberatory furnace. The present 832 electrolytic tanks provide an output of some 60,000 tons of refined copper per annum, but this capacity is about to be doubled. The enlarged plant will be essentially similar to that which

has been in operation for the past fourteen years. The new Clarke wheel will, however, be designed primarily for the production of vertically-cast shapes, and it is understood that the production of oxygen-free high conductivity copper is under consideration.²⁴

Other valuable plant and process descriptions include an account of the Phelps Dodge smelter at Morenci²⁵ and an interesting report of the recovery of sulphur from smelter gases at Rio Tinto,²⁶ where the Orkla process, which originated in Norway, is in use. The basic reaction is the reduction of sulphur dioxide to sulphur by carbon in the upper parts of the blast furnace.

While the practical aspects of copper smelting are very well understood, surprisingly little is known of the fundamental reactions which occur in the various stages of the process. Two important papers by Peretti concerned with the underlying thermodynamical principles are, therefore, particularly welcome. These deal respectively with roasting and converting.

In order to study the changes which occur during roasting Peretti²⁷ made cylindrical briquettes of uniform size from chemically pure cupric sulphide powder and heated them for various times at a series of increasing temperatures. He afterwards sectioned the briquettes and measured the diameters of the visible phase boundaries, thus establishing the effect of temperature on the rate at which the reactions proceeded. It was concluded that at all temperatures from 430°-965° C., the first stage in the roasting of cupric sulphide consisted of simple decomposition into cuprous sulphide and sulphur. Not until this reaction was complete did oxidation of the resulting cuprous sulphide commence. This occurred by the conversion of the outer layers of cuprous sulphide into cuprous oxide, with the evolution of sulphur dioxide. An envelope of cuprous oxide was formed in this way, and grew to a certain definite thickness of from 0.5-1 mm., depending on the temperature. This envelope then moved inwards through the briquette at a uniform rate for each temperature, but did not increase in thickness, the parts outside it being converted to cupric oxide. At temperatures of about 570° C. and below, increasing amounts of copper sulphate were associated with the cupric oxide, and, by hindering the inward diffusion of oxygen, brought the process almost to a standstill. Yet even under these conditions the narrow intermediate zone of cuprous oxide was apparently maintained between the inner unchanged core and the outer mixture of cupric oxide and sulphate, and Peretti points out that this brings his observations into sharp conflict with the widely accepted views of Ashcroft,²⁸ who maintained that "reactions in roasting proceed primarily and definitely to the formation of sulphates, not oxides, the latter as well as the sulphur dioxide evolved being secondary products, formed by the decomposition of the sulphates."

The second of Peretti's papers²⁹ which deals with the reactions occurring in the converter, is more speculative in character than that just described. By the application of thermodynamical considerations to the slag-forming stage, it is shown that the ratio of the partial pressure of sulphur dioxide to that of oxygen in the blast can become very large before equilibrium is reached. For this reason, when blowing with air, the oxygen utilisation could theoretically be almost complete, as indeed it is in actual practice. Peretti goes on to discuss the blister forming stage from the point of view of the copper-sulphur equilibrium diagram, and gives a credible

thermo-dynamical explanation of why bottom-blown copper converters have never given successful results.

Melting and Casting

As in the case of smelting and refining an important symposium has been held, this time by the Institute of Metals, on the melting and casting of ingots for working. Apart from the first paper in which Bailey and Baker present a very able and complete review of the factors which contribute to the production of good quality castings for subsequent working operations, the remaining five are all concerned directly with copper and its alloys. In the space at present available it is impossible to do more than give a brief outline of each of the papers all of which merit careful study.

As already stated, the opening paper of the series³⁰ covers the entire field of the chill casting of non-ferrous metals and alloys in the forms required for subsequent fabrication. After a description of the more common defects in ingots, the authors trace the mechanism of solidification in metals and alloys and then proceed to give practical recommendations on such subjects as the elimination of dissolved gases and non-metallic inclusions, the advantages and disadvantages of various methods of pouring and the effects of both macro- and microstructure. Reaction-gas unsoundness can usually be dealt with by increasing the oxygen content of the melt, and then treating with a powerful deoxidant while inclusions, such as metallic oxides, can generally be eliminated by the use of suitable fluxes which dissolve, or at least wet, the oxides. Various methods of pouring are described and stress is laid both on non-turbulent methods, such as the Durville process, and directional solidification with special reference to continuous casting.

Each of the five remaining papers deals with a particular class of copper-base materials, and each of the authors is able to write with the authority of personal experience.

Waddington³¹ describes in detail the methods practised at the Copper Cliff works of the International Nickel Company of Canada for the melting of copper cathodes and subsequent casting into wire bars and other shapes, for fabrication.

The equipment comprises two direct arc furnaces, each capable of melting over 15 short tons of copper per hour, two enclosed pour hearths heated by low-frequency induction, and two casting wheels equipped to take the 36 different types of moulds normally required. The melting process is continuous and no refining or slagging operations are involved. Copper cathodes weighing 265 lb. are charged at the rate of two per minute through a slot in the furnace, and under their displacing action, metal flows from the tap hole into the pour hearth, whence it passes to tilting ladles and so to the moulds. "Pitch" is regulated by a slow stream of air drawn through the furnace. Technical control is excellent throughout the process, the success of which depends on the meticulous care which is exercised.

At the works of Messrs. J. Stone & Co., Ltd., the production of aluminium bronze ingots for subsequent working is likewise under careful control. Murphy and Callis³² emphasise that an important aspect is the avoidance of entrapped oxide films and gas porosity. The first of these difficulties is largely overcome by the Durville process, while the introduction of gas into the melt from the furnace atmosphere can be minimised by ensuring that the protective film of alumina which forms on the surface of the melt remains undamaged. For

this reason the use of fluoride-containing fluxes, which dissolve the film is regarded as undesirable.

The paper by Bond-Williams³³ on the flux degassing of phosphor bronze for the casting of slabs and wire bars describes the institution of refined methods of production, based on the results of modern research. Important features are the adoption of coke-fired pit furnaces of the Wigley type, which provide more oxidising conditions of melting than those of orthodox construction, and the addition of an oxidising flux consisting of equal weights of dry sand, copper mill scale and fused borax.

The description by Cook and Fletcher³⁴ of the melting and casting of brasses is broad in its scope and deals with principles and recommendations rather than with specific details of practice. The advantages of the low-frequency induction furnace for the melting of brasses are stressed, and it is pointed out that brasses are less susceptible to gas unsoundness than most other copper-base alloys because of the scavenging action of the volatile zinc. Copper-faced water-cooled moulds of the Junker type are recommended in preference to those of cast iron, while flaming dressings are advocated because they provide reducing conditions in the mould as soon as the metal enters it. Brief mention is made of the application of continuous casting methods to brass.

The final contribution to the Symposium³⁵ traces the casting of nickel silver at the works of Messrs. Henry Wiggin & Co., Ltd., from 1833 onwards, and describes current practice in detail. Both coke-fired furnaces of the Wigley type and oil-fired lift-out furnaces are in use. It is somewhat surprising to learn that graphite crucibles have been abandoned in favour of those made from silicon carbide because of the lower thermal conductivity of the latter. They are claimed to have the advantage of minimising heat loss when pouring several ingots from the same pot of metal. All strip ingots are now cast in copper-faced water-cooled moulds, dressed with a mixture of rape oil and charcoal dust. Deoxidants are manganese and phosphor copper, which latter is said to eliminate cracking during annealing.

The Symposium discussion was both lively and informative.

On much the same lines as several of the papers in the Symposium is the description by Trector and Martland³⁶ of the casting of marine propellers by the Randupson and sand-cement process at the works of the Manganese Bronze and Brass Co., Ltd. The moulds are prepared from a mixture of pure silica sand and ordinary Portland cement.

Several further papers concerned with founding work deserve mention. One of these, by Caudron,³⁷ is remarkable in advocating the melting of copper-base alloys in a reducing atmosphere instead of under the more usual oxidising conditions, with the object of minimising the formation of slag. Gas porosity is avoided by the simple expedient of blowing compressed air through the melt for from $\frac{1}{4}$ – $1\frac{1}{2}$ minutes before pouring and then adding a suitable deoxidant such as phosphor copper. Equally provocative is the application by Lepp³⁸ of thermo-dynamical principles to the casting of tin bronzes. For the elimination of dissolved gases he advocates selective oxidation using carbonate fluxes, which not only act as carrying solvents for the introduction of a controlled percentage of cuprous oxide into the melt but also eliminate sulphur and stannic oxide from it. Pell-Walpole³⁹ has given an excellent review of inverse segregation in non-ferrous alloys and has assessed the

possibilities and limitations of the heat treatment of foundry bronzes,⁴⁰ while Berridge,⁴¹ Nixon⁴² and Caine⁴³ have each made practical recommendations concerning the running and feeding of copper-alloy castings. The last named outlines a system for positioning the risers and gives an empirical equation for computing their most suitable dimensions.

The Technical Committee of the Association of Bronze and Brass Founders⁴⁴ has followed up the issue of B.S. 1367 "Code of Procedure in the Inspection and Testing of Copper-base Alloy Sand Castings" and B.S. 1400 "Schedule of Copper-Alloy Ingots and Castings" by the publication of tests on a number of typical castings taken from normal production. Tensile data on specimens cut from the actual castings were compared with those on separately cast bars and with the requirements of the specification. The results are voluminous and the publication provides a valuable standard of reference, affording a more systematic insight into the properties which can be expected from commercial castings in relation to results on test bars than has been available until now.

Fabrication

In connection with the Fourth Empire Mining and Metallurgical Congress, Desch⁴⁵ presented a thoughtful paper on the cold working of metals, giving a clear, comprehensive and very readable review of fundamental theories and modern research techniques. It is commended to the attention not only of research workers but also of practical men who desire a better understanding of the behaviour of metals and alloys during fabrication at ordinary temperatures.

Not long ago a comprehensive investigation undertaken by the B.N.F.M.R.A., did much to elucidate the mechanism of the well-known embrittlement of phosphorus deoxidised copper by bismuth, and a recent contribution by Hallows⁴⁶ treats the same subject from the practical angle and outlines techniques for overcoming this difficulty in the commercial production of strip and tube. The recommendations set out in the paper can be regarded as a valuable insurance against a contingency such as that which occurred during the war, when this country was forced to utilise considerable quantities of fire refined bismuth-bearing copper.

By the use of composite billets, and especially of plugs inserted in the outside of billets, Blazey and his collaborators⁴⁷ were able to study the flow of metal during the extrusion of tubular sections. They differentiated clearly between the lubricated type of flow in which the billet moves relative to the container and the non-lubricated type where the skin of the billet remains in place against the container wall. A layer of oxide on the surface of a copper billet tends to promote lubricated flow, because the metal can slide within the skin of oxide, but brass and cupro-nickel behave like unoxidised copper in a non-lubricated container. From a practical point of view, the principal distinction between the two types of flow is that superficial defects on the billet are likely to appear between the walls of the tube shell with the non-lubricated type, and on the outer surface of the shell with the lubricated type, and that double or blistered walls may arise with the lubricated type.

This is an opportune moment to welcome the inauguration of the Indian Institute of Metals, for the first issue of their transactions includes a useful description of the production of seamless non-ferrous tubes.⁴⁸ Details

are given of the dimensions of billets, die sizes and drawing schedules which have been found by experience to give satisfactory results, and the paper should, therefore, provide a valuable guide to the installation of new plant for tube production.

A new tube-drawing machine, believed to be the first of its kind ever built, has recently been put into operation⁴⁹ for the manufacture of brass and copper tubes. It is fully automatic, with push-pointing mechanism. Another interesting machine has also been installed in this country.⁵⁰ This is capable of drawing, straightening and cutting to length brass rods in continuous sequence. It can handle round stock up to 1 in. in diameter, and slightly smaller sizes of hexagon or square bar, and combines high speed of output with excellent surface finish of the rod produced.

Attention has again been directed to the cold extrusion process in an article by Lloyd and Kopecki⁵¹ who point out that it can be applied to most types of steel and that it has the important advantages of economy of material and close dimensional accuracy. It seems evident that as such methods have been adopted with economic success for steels, they should be even more satisfactory for copper and its alloys which are intrinsically easier to deform. Though some use of the process has already been made in the copper industry, cases are relatively isolated. For instance, cold "hobbing" under pressure has already been applied to the production of moulds in beryllium copper, aluminium bronze, and similar alloys. A development of this is the pressure of a "hob" into beryllium copper as it solidifies from the molten state.⁵²

Finishing and Plating

Little that is worthy of comment seems to have been published in connection with the finishing of copper and its alloys, but a warm welcome must be accorded to the new book by Hoare of the Tin Research Institute on Hot Tinning.⁵³ One chapter deals entirely with the tinning of copper and provides a thorough review of the various techniques employed industrially, except electro-tinning which is outside the scope of the book.

Last year's review included a description of a British technique for the electrolytic polishing of small brass articles on a commercial scale, and a somewhat similar method has now been reported in America.⁵⁴ The articles are wired on racks which rotate in an electrolyte consisting of orthophosphoric acid, glycerol, ethylene glycol, lactic acid and water with small additions of other organic chemicals to improve the brightness of the polish and increase the throwing power of the solution. The stainless steel containers which form the cathodes are protected from accidental contact with the rotating racks by porous ceramic linings, while cooling coils are fitted between the containers and linings to maintain the bath at about 98° F. Details of operating currents and voltages are not given.

Banerjee and Allmand⁵⁵ have reported an extensive series of experiments on the electrodeposition of brass from cyanide solutions. Alloys containing from less than 1% to over 99% of copper were deposited and their structures were examined by X-ray methods.

In describing the practical aspects of plating in the spoon and fork trade, Hill⁵⁶ points out that, prior to the war, many spoons and forks were made of brass or low-grade nickel silvers containing no more than 5% of nickel. A recent proposal demands that table-ware which is marked "Nickel Silver" or "E.P.N.S." shall

conform to B.S. No. 790 and contain not less than 10% of nickel. Hill gives details of two fundamentally different methods of producing spoons and forks, known respectively as stamping and pressing. In the older stamping operation the required shape is formed from a blank whose thickness corresponds with that of the thickest parts, or rib, of the articles to be made, while in the more modern pressing process the blank is of the thinnest section required in the stail, which is subsequently thickened where necessary by lateral pressure. Full details of normal plating processes form a major part of the paper, while modern methods of bright plating and electrolytic polishing, including the protection of silver from tarnishing by means of an invisible film of beryllium oxide, are also outlined.

Properties of Copper and Copper Alloys

Creep of Copper.—Additional information on the creep properties of various commercial coppers has been provided by Schwope, Smith and Jackson⁵⁷ who investigated both tough pitch and oxygen-free high conductivity grades with and without additions of 0.04 and 0.07% of silver in each case. Each material was tested after degrees of cold reduction ranging from 5–40%. The temperature was 300° C., and most of the tests were of relatively short duration, averaging about 24 hours. They were, however, continued until a "secondary or minimum creep rate was well established." These short-time tests were correlated with more prolonged experiments in certain cases, and the results indicated that they gave, on the whole, reliable results. This is perhaps the most important conclusion from the work, for the experimental data themselves do little beyond confirming the known beneficial effects of silver in raising the recrystallisation temperature and improving the creep resistance.

Embrittlement by Bismuth.—Supplementing earlier researches on the effect of bismuth on copper, Hallows⁵⁸ of the British Non-Ferrous Metals Research Association has described the effect of this undesirable element on the tough pitch grade. The presence of oxygen reduces the embrittling effect of bismuth and lowers the temperature at which maximum embrittlement occurs from about 550° C., in the phosphorus deoxidised variety to about 350° C. Even at this temperature embrittlement of tough pitch copper does not become serious unless the material is first rapidly cooled from 750° C., or above and cold worked. Annealing in the usual temperature range of about 450°–650° C. causes the bismuth to combine more or less rapidly with oxygen, rendering it relatively harmless. The same effect is also apparent at lower temperatures, so that prolonged heating of brittle material at 350° C. promotes a slow return to the ductile condition. With normal grain size and under the most adverse condition outlined above the embrittlement of tough pitch copper may be severe with bismuth contents exceeding about 0.0035%, but with lower concentrations it is unlikely to have much practical significance. It may be recalled that earlier publications by the B.N.F.M.R.A. on this subject attributed embrittlement to the formation of a thin film of metallic bismuth at the grain boundaries of the copper. Some doubt has been cast on this interpretation by the investigations of Ké⁵⁹ and of Samuels,⁶⁰ and it now seems possible that embrittlement may be caused by the concentration, without actual precipitation, of bismuth at or immediately adjacent to the grain boundaries.

Beryllium Copper.—Several contributions to knowledge of the precipitation hardening of beryllium copper have been reported. Hunger, Pawlek and Seeliger⁶¹ used the electron microscope to study the ageing process both in the alpha ground mass and in eutectoid. The observations were correlated with changes in micro- and macro-hardness. Unkel⁶² carried out a series of practical tests of the effects of different annealing temperatures and times on the mechanical properties and electrical resistance of drawn, forged, hot and cold-rolled samples, while Beck⁶³ investigated the rate of precipitation hardening with special reference to the effect of additions of cobalt and chromium. Both of these elements tend to localise precipitation at the grain boundaries, with lower peak hardness and faster over-ageing. To combat this effect the use of relatively high solution heat treating temperatures is advocated. Richards⁶⁴ gives advice concerning the machining of beryllium copper.

Aluminium Bronze.—A comprehensive series of tests on the mechanical properties of aluminium bronzes at temperatures from –180° to 540° C., together with measurements of thermal expansion has been published by the Battelle Memorial Institute.⁶⁵ Three typical compositions were used; an 8% alpha aluminium bronze, a 10% duplex alloy containing iron, and a high strength material carrying nickel and manganese as well as iron. It was found that the strength was highest at subnormal temperatures and dropped off rapidly above 315° C., accompanied by a marked increase in elongation. Impact values were highest for the alpha alloy. Welded materials showed lower impact and elongation values at subnormal temperatures than alloys in the wrought, unwelded condition.

Although the advantages of adding lead to aluminium bronze with the object of improving machinability are recognised, an opportune reminder is provided by the recent work of Grodsky⁶⁶ who investigated the effect of up to 3% of lead on 10% aluminium bronze containing 3% of iron. The author concludes that between 0.5 and 1% of lead may safely be added to aluminium bronze, greatly improving its machinability without serious detriment to its mechanical, heat treating, forging or welding characteristics.

Grain Size of Brass.—As the result of an investigation of the effect of grain size on the strength elongation and fatigue resistance of deep drawing brass sheet, Walker and Craig⁶⁷ conclude that grain sizes smaller than are usually achieved by industrial rolling practices have a very marked and beneficial effect on all but the ductility properties. The endurance limit for 10⁸ cycles is almost doubled when the average grain size is reduced from 0.024–0.004 mm.; consequently the control of grain size for such applications as diaphragms, or where vibration is an important factor, may materially improve the life of the parts. This statement needs qualifications from the work of Entwistle⁶⁸ who shows that the damping capacity of alpha brass is relatively low when the grain size is small, so that free vibrations induced in such material would continue longer than in similar brass of larger grain size before dying away.

Alloys Containing Manganese.—Though unlikely to be of much practical value, it is interesting to note that certain copper - manganese - gallium and copper - manganese-germanium alloys are, like the well-known Heusler alloys, magnetic.⁶⁹ Of more commercial significance is a patent claim that brasses comprising 53–75% copper with at least 5% each of nickel and

manganese, the sum of these two elements being between 12 and 20% of the whole, are superior in colour and mechanical properties, including fatigue resistance to the nickel silvers.⁷⁰ It is possible that such materials, like those in the ternary copper-nickel-manganese system might be heat treatable, though no claim to that effect seems to have been made. A new alloy containing 60% of zinc with 25% of manganese, 15% of copper and a little aluminium is reported to have been successfully used for die casting,⁷¹ while mention should also be made of a new hardenable alloy comprising copper with 10% each of nickel and manganese and 1% of iron.⁷² It is said to be exceptionally resistant to sea water, and therefore appears to combine the advantages of the hardenable copper-nickel-manganese alloys with the corrosion-resistance of the copper-nickel-iron series. No further details are yet available.

To be continued.

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MOND NICKEL FELLOWSHIPS

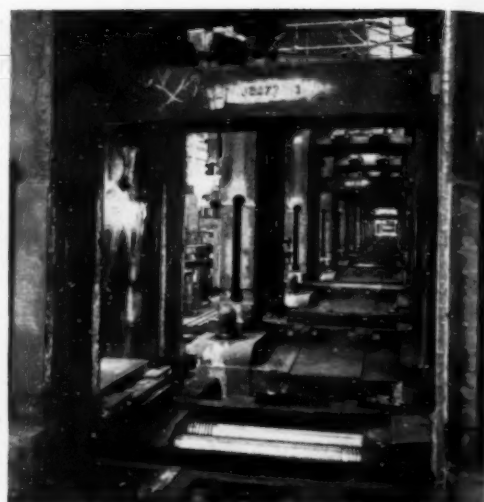
THE Mond Nickel Fellowships Committee announces the following two awards for 1949:—

MR. J. MONAGHAN (Stewarts and Lloyds, Ltd.); to study the method of control and administration of basic open-hearth operation and practice in the steel industry in the United States of America.

MR. R. STEWARTSON (The United Steel Companies, Ltd.); to study the design and operation of modern hot-rolling mill plant in the United States of America. The Mond Nickel Fellowships Committee will at a later date invite application for awards for 1950. Full particulars of the Fellowships can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1.



A Morgan continuous merchant and rod mill plant of 23 stands, claimed to be the fastest rod mill in the world, being dismantled for transporting to South Wales.



A rather unusual view of the stands of this mill taken during the dismantling operations.

World's Fastest Rod Mill Nears Completion

A highly mechanised mill which is capable of matching the present unprecedented demand and affording considerable economies in power and fuel consumption.

NOW in process of delivery from a Sheffield Works to the well-known South Wales Steel Plant of Guest, Keen and Nettlefolds, Ltd., is the world's fastest rod mill. This mill is a Morgan continuous merchant and rod mill plant of 23 stands built in the Darnall Works of Davy and United Engineering Company Limited. It will produce all sizes of rods from 5 gauge up to $\frac{3}{8}$ in. diameter and coiled bars up to 1 in. diameter and will have a sustained output of 25 tons per hour of No. 5 gauge rods and 50 tons per hour of size $\frac{1}{2}$ in. and above.

The two essential conditions of this new mill have been first, that both rods and bars should be produced free from all rolling defects and, in the case of bars, to a close tolerance, and secondly that it should be capable of producing consistently the above weekly output. In this mill the novel method of reduction employed will ensure a uniformly excellent product, defect-free and within the tolerances required, while the finishing speed, on which output depends, will be as high as 5,000 feet per minute. Compared with this mile-a-minute mill, the fastest American mills of similar type have maximum delivery speeds of only about 4,400 feet per minute.

The mill itself consists of an 11-stand roughing mill, a 2-stand intermediate mill, a 4-stand looping mill and a 6-stand rod finishing train, together with a host of auxiliary equipment in the shape of a continuous billet heating furnace, pouring and laying reels, coil conveyors, shearing equipment and so forth. Highly mechanized mills of this type offer advantages to Britain's steel industry which at the moment are both important and opportune in overcoming prevailing man-power shortages providing outputs capable of matching the present unprecedented demand and affording considerable economies in power and fuel consumption. This new mill's performance will therefore be watched with added interest.

The primary intention is to roll low-carbon, high-carbon, and low-alloy steels, but the mill has in fact also been designed to roll alloy and stainless steels should such products be called for in the future.

Spheroidal Graphite Cast Iron Patents in United States and Great Britain

THIS new material referred to in the article on p. 84 can be made readily and economically, and can be used for many applications in engineering practice, in building, and for general and domestic purposes. Its use for improving the conventional grey iron castings and for the replacement of malleable cast iron and even in some cases of steel and other alloys, is rapidly becoming established. It is, undoubtedly, the major development in the iron founding field in recent times.

U.S. Patents Nos. 2,485,760 and 2,485,761 covering the new cast iron, have been granted recently to the International Nickel Company. Three British applications Nos. 630,070, 630,093 and 630,099 in the name of the Mond Nickel Company, have been accepted by the British Patent Office. Patent applications have been made in all other leading industrial countries, and have already been granted, among others, in Belgium, Italy and South Africa. Already over 40 firms have been licensed to make the new iron in the U.S.A.

Licences for the production of the new iron in Great Britain have now been granted to Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield; Robert Taylor & Son (Ironfounders), Ltd., Larbert, Stirlingshire, Scotland; Lloyds (Burton), Ltd., Wellington Works, Burton-on-Trent; and W. A. Baker & Co., Ltd., Newport, Monmouthshire; and doubtless others will shortly be granted.

Recent Developments in Materials Tools and Equipment

Vermiculite High-temperature Insulating Bricks

IN recent years considerable attention has been given to the conservation of heat and much experimental research has been carried out to ensure proper insulation of the vehicle used for transferring heat with the least possible loss. Of the many insulating materials employed for this purpose the most recent is vermiculite, which has such remarkable properties that its use as a insulating material, particularly for high temperatures, is proving to have outstanding merits. Although it has been used for some time as an insulating material in the building of dwelling houses, its application as a refractory insulating material has only recently been developed, largely as the result of investigations carried out by Thomas Marshall & Co. (Loxley), Ltd., brief reference to which will be of interest.

The name vermiculite, as is fairly well known, is applied to a group of minerals that give off water and expand greatly—in commercial grades as much as 16 times in one direction—when heated. The best qualities bulk 6 lb. or less per cub. ft. after being exfoliated, forming cork-like pellets that resist abrasion. Originally mined in America and developed, in the exfoliated condition, vermiculite was being used extensively in that country before the war as a loose fill for low-temperature and sound insulation for building construction, but not in brick form. Later its possibilities as a refractory were investigated; for this purpose Thomas Marshall & Co. obtained permission to import a small consignment from South Africa, where a deposit had been proved, just before the recent war. The object of the Company was to carry out experimental work, but owing to difficulties in obtaining suitable machinery for sizing and dressing, and the need at that time to concentrate research on more pressing problems, little was done with the material until 1946. By that time the mines in South Africa had developed and had installed dressing and screening equipment, and the Company was able to obtain a more suitable product with which to continue the experimental work. The results obtained from the investigation were so successful that, by the end of 1947, the Company had solved the main problems of the manufacture of insulating brick, using vermiculite as the main constituent.

Since that time, the Company has been producing bricks and tiles on a pilot-plant basis, having designed its own type of furnace for the exfoliation process and

installed specialised forming and kilning plant. Output is now at the rate of 10,000 $9 \times 4\frac{1}{2} \times 3$ in. bricks per week and can be stepped up rapidly according to market requirements.

The bricks manufactured from this plant are remarkably consistent in their properties, this is particularly important in view of the difficulties experienced by the Americans in obtaining consistent results. It may be that the source of the raw material is an important factor in the success achieved in this direction. Vermiculite brick as produced by Kingscliffe Insulating Products, Ltd., a subsidiary of Thomas Marshall & Co., has a maximum safe working temperature of 1,100° C. and can be made in bulk densities ranging from 24–28 lb./cu. ft., according to the application for which the bricks are intended. The main properties of these bricks, which are marketed under the name of Victor Bricks, are as follows:—

VERMICULITE HIGH-TEMPERATURE INSULATING BRICKS.
PROPERTIES OF VICTOR BRICKS

Type	8d.	40	48
Density (lb./cu. ft.)	29	40	48
(gm./c.c.)	0.46	0.64	0.77
Cold Crushing Strength (lb./sq. in.)	120	200	250
Maximum Service Temperature Recommended °C.	1100	1100	1150
°F.	2000	2000	2100
After-contraction at Maximum Service Temperature	nil	nil	Less than 1%
R.T.U./sq. ft./hr./1° F. at Mean Temperature of	240° C		
300	1.16	1.69	1.76
400	1.23	1.77	1.83
500	1.32	1.86	1.91
600	1.41	1.95	2.01
700	1.51	2.06	2.12
850	1.57	2.12	2.18



Some typical examples of vermiculite insulating bricks and slabs showing the wide variety of shapes available

The above figures are averages of routine tests carried out over a year's working, taken from production control charts. The thermal conductivity figures are averages of a number of tests in an apparatus calibrated against National Physical Laboratory results.

It will be noted that the properties of these bricks are at least equal, and often superior to a porous firebrick of the same density, but in the lower density range their very low heat capacity is of great importance. One advantage of the vermiculite brick is the fact that it can be produced in quite large slabs (e.g., $18 \times 9 \times 4\frac{1}{2}$ in.) or almost any rectangular shape without resort to cutting or machining after forming, whereas the normal type of porous firebrick has severe limitations in this respect. On the other hand, if the bricking should be particularly complicated and the bricks or slabs have to be shaped, they can be cut or drilled very easily with ordinary woodworking tools.

Finally, the bricks are extremely accurate in shape and size and consequently the minimum amount of jointing need be employed, which is a feature likely to be appreciated by furnace builders. A suitable insulating jointing cement incorporating vermiculite has been evolved for jointing purposes.

These products seem to be a very useful addition to the high-temperature insulating brick range and their many useful properties are bound to commend them to designers of industrial plant of all descriptions working at high temperatures.

A Mullard Ultrasonic Soldering Iron

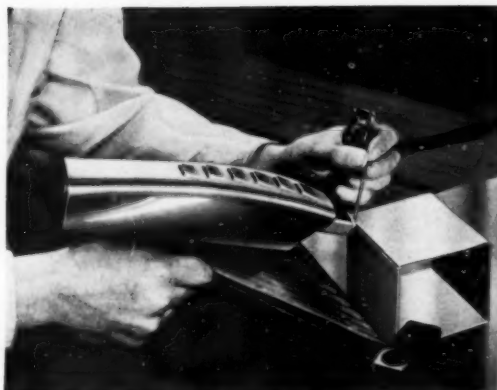
THE soldering of aluminium and other light metals and alloys is made easy by means of an Ultrasonic Soldering Iron, Type E7587, recently announced by the Electronic Equipment Division of Mullard Electronic Products, Ltd.

Developed in the Mullard Electronic Research Laboratories, this device consists essentially of a removable copper soldering bit and a magnetostriction transducer. The soldering bit which is heated by means of a conventional resistance winding, is secured to a brass block held in firm contact with the nickel core of the transducer. The ultrasonic power necessary to drive the transducer is supplied by an electronic amplifier comprising the power supply unit.

In this new soldering iron the problem of temporarily destroying the refractory oxide film, which forms on most light metal and alloys, is solved by ultrasonic stimulation. This provides a clean surface and greatly facilitates the soldering of aluminium and other metals which form refractory oxides.

The soldering iron is simple to use, and has the advantage that no flux is required, and that standard soft solders may be employed. To avoid electrolytic action, however, it is advisable to use a solder with a tin-zinc base instead of the usual tin-lead alloy.

In application, the soldering bit is allowed to heat to the usual operating temperature. The transducer is then energised, and the bit is tinned by applying a soft solder. After this, soldering is carried out in the normal way, care being taken to maintain a good liquid contact between the bit and the work. This ensures the maximum acoustic efficiency, and enables positive and uniform joints to be obtained.



Applying the ultrasonic soldering iron

The ultrasonic frequency chosen to operate the bit is well above the normal audible range, so that no discomfort is experienced by the operator.

This new Ultrasonic Soldering Iron, which is the first commercial model of its kind in the world, should prove of particular value in the aircraft, civil engineering, shipbuilding, and hardware industries—and in fact all manufacturing industries where the successful soldering of aluminium and its alloys has for so long been a pressing production problem.

Mullard Electronic Products, Ltd., Century House, Shaftsbury Avenue, London, W.C.2.

Obituary

Mr. J. P. D. Coleman

It is with regret we have to record the death on Sunday, November 20th, of Mr. J. P. D. Coleman, a director of Wild-Barfield Electric Furnaces, Ltd. from 1933, until his retirement in 1948. Starting his long connection with the electrical industry in 1896 when he joined the National Telephone Co., he served under the late Mr. E. P. Barfield, an association which was almost continuous until the latter's death in 1938.

After completing his apprenticeship, he had a period of sea-going service, and in 1910 joined the cable department of Siemens Bros. & Co., later transferring to Siemens Bros. Dynamo Works. During the 1914-18 war he served with the Royal Engineers and afterwards rejoined Mr. Barfield in 1919, becoming works manager in the Company formed through the collaboration of Mr. Barfield and Mr. L. W. Wild to manufacture electric heat-treatment furnaces. He was appointed to the Board as works director in 1933 and joined the Board of the Associated Company, G.W.B. Electric Furnaces, Ltd. in 1938. During the last war, he volunteered and served for a short time with the R.N. motor-fishing vessels.

In 1945, he gave up active day-to-day participation in the business, but remained on the boards of both companies until, on account of ill-health, he resigned his directorships in 1948.

His death so soon after his retirement will be regretted by the very large number of friends he made not only in the electrical industry but in the many other fields with which his work brought him into contact.

Reviews of Current Literature

BRITISH IRON AND STEEL FEDERATION'S STATISTICAL YEAR BOOK—OVERSEAS SECTION

Giving details of production and trade in iron and steel for 32 countries in 330 tables, it contains 337 pages, with 11 maps; it is published by the British Iron and Steel Federation, Steel House, Tothill Street, London, S.W.1, price 15s.

PUBLICATION of the Overseas Section of this Statistical Year Book was resumed last year, after a lapse of nine years owing to the war. In the preface to that volume, reference was made to the difficulties encountered in the attempt to bridge the war-time gap and to present a complete statistical picture for 1946. The present volume carries the story on to 1947 and represents what can be regarded as the most comprehensive statistical guide to the iron and steel industries of the world. The edition preserves continuity with pre-war volumes, but is even more complete than its predecessors. Unavoidable gaps unfortunately remain—particularly in the Russian statistics—but every effort has evidently been made to provide as comprehensive a service as possible. A particular feature of the present edition is the inclusion for the first time of maps illustrating the iron and steel industries of the more important countries. It includes tables of the world production of iron and steel since 1866 and of iron ore since 1929.

The late publication of the figures given is regrettable, but it will be appreciated that this is a reflection of the abnormal delay which still occurs in many countries before official statistics are issued, and it is hoped that the time-lag will be less in future years.

ALLOY SYSTEMS

By James Osborn Lord: Pitmans Metallurgy Series; Frank T. Sisco, Advisory Editor. 1949; pp. 380; price 40s, net. Published by Pitman Publishing Corporation, New York, London. Sir Isaac Pitman & Sons, Ltd., Kingsway, London, W.C.2.

ALTHOUGH its title might mislead one into expecting something different, this is in fact a very elementary textbook of physical-metallurgy. The book is pleasant to read, the author adopting a rather genial and less austere style than is customary in technical writing while retaining real clarity of presentation. The topics covered never take the reader out of touch with essentially practical or engineering metallurgy and the newer ideas often grouped as "metal physics" have hardly a mention. Thus there is but a passing mention of slip, only a very superficial touching upon crystal-structures, and theories of alloy formation are confined to less than a page on Hume-Rothery's electron compounds. At the same time the manufacture of steel is only covered very briefly, and there is nothing about the working or forming of metals. Chapters on copper, brass and bronze, aluminium, magnesium and their alloys are short, but not too narrowly restricted in interest. On the other hand there are much fuller and, for an introductory book of this type, excellent accounts of the heat treatment (and S-curves) of plain and alloy steels (104 pages) and of the phase-rule and its use in equilibrium and metastable systems (41 pages). It appears, in fact, the Author's object to reveal the breadth rather than the depth of his subject, and this without an appearance of scrappiness.

Perhaps the questions following each chapter illustrate better than anything just how far into its subject the

book does go. Typical examples are "Can a eutectic structure be segregated? Explain," or "How should coarse grain size in manganese steel affect the S curve?" or even "Name an outstanding characteristic of tungsten carbide." After a few not very strenuous evenings with this book a newcomer to physical metallurgy should be at least prepared for sensible consideration of such problems.

In fact, the book makes its appeal to engineers or metallurgical students seeking a first easy survey of theoretical metallurgy. To such the price, enhanced by the rate of exchange, is going to be an almost complete deterrent, as equally excellent books covering the same field can be bought in this country for less than half this cost. On the other hand this may well prove a useful addition to technical or college libraries where it will satisfy the requirement of those wanting a second and possibly easier treatment of one of the themes which this book does well to complement their other texts, and where jaded students of other subjects may find in it, in gentle and easily read form, the metallurgy they may require.

G. A. GRACH.

METALLOGRAPHE DES MAGNESIUMS UND SEINER TECHNISCHE LEGIERUNGEN

By Walter Bulian and Eberhard Fahrenhorst, published by Springer Verlag, Berlin, 1949; pp. 140, 250 illustrations; price DMark 16.50. (In German).

This book is number eight in the publishers' series on pure and applied metallurgy, edited by W. Köster. It deals comprehensively with the metallography of magnesium and its alloys, which have acquired considerable industrial importance in the last decade. The authors need little introduction as they are well known for their research work at the Wintershall A. G. A brief introduction gives the reader a general picture of the alloys dealt with, these being divided into two classes, those which contain aluminium and those which do not. In the following chapters the authors show, with the aid of 225 photomicrographs, the information to be obtained by the microscopic examination of these materials and indicate the extent to which such examinations may be relied on for information on the type of alloy, previous mechanical and thermal treatment and defects in composition and manufacture. The contents include details of polishing and etching techniques, macro-structure and fractures. Within a relatively small book the authors deal with a wide range of subject-matter and numerous references to the technical literature, in which specific aspects are treated more fully, are given. These, as well as a name and subject index, add greatly to its value to all who wish to obtain a critical and complete account of the subject.

F.N.

THE NICKEL BULLETIN

A SHORT article on the important Nimonic series of alloys appears in the November issue of the Nickel Bulletin. Their excellent creep-resisting properties are now appreciated by the designers and engineers in the aeronautical field; applications in other fields, where high strength at high temperature is required, are also discussed.

The Bulletin may be obtained, free of charge, on application to: The Mond Nickel Co., Ltd., Sunderland House, Curzon Street, W.1.

Staff Changes and Appointments

MR. A. M. LEIPER, M.I.Mech.E., chief engineer of Hadfields, Ltd., has been appointed a local director. Mr. Leiper joined Hadfields in 1948 from the Ordnance Factory Organisation in India, where he held the post of deputy director of factory expansion, and was later superintendent, I.O.F., Amritsar.

MR. W. R. P. KING, works manager of The Mint, Birmingham, Ltd., has been elected a Fellow of the Institution of Works Managers. He has also been re-elected chairman of the West Midland Branch of the I.W.M. for 1949-50.

DR. I. G. SLATER has resigned his position as Director of Operational Research, Admiralty, and has joined Tube Investments, Ltd., as Director of Research and Development of its Aluminium Division. He will be attached to the administrative and marketing organisation of T.I. Aluminium, Ltd., and will also be connected with the research and development of the concern's subsidiaries, Reynolds Rolling Mills, Ltd., Reynolds Light Alloys, Ltd., and the South Wales Aluminium Co., Ltd.

MR. E. F. NEWELL has retired from Messrs. Quasi-Arc Co., Ltd., after thirty years service with them; first as metallurgist and later as sales director in charge of Home Sales, Technical Services and Publicity. Mr. Newell intends to practice as a Consulting Metallurgist, at present operating from Cranmere House, Woodthorne Road, Tettenhall, Staffs.

MR. S. W. RAWSON has been appointed a Managing Director of Messrs. John Brown & Co., Ltd., of Sheffield. Mr. Rawson's headquarters will be in London.

MR. D. R. G. DAVIES has returned from America and has taken up his duties as Chief Metallurgist at the Redbourn Branch of Richard Thomas & Baldwins, Ltd., Scunthorpe, Lincs.

DR. J. P. DENNISON has been appointed Assistant Lecturer in Metallurgy in the University of Leeds.

MR. N. G. LANCASTER, M.B.E., A.C.A., who was elected to the Board of Tube Investments, Ltd. in April, 1949, has been appointed an Assistant Managing Director.

SIR GEOFFREY BURTON has been elected to the Board of Tube Investment's new subsidiary company, T.I. Cycles (South Africa), Ltd.

MR. D. P. CARR, Trackwork Department, Edgar Allen & Co., Ltd., has been elected Chairman of the Sheffield Committee of the Permanent Way Institution, whose Annual Conference will be held in Sheffield in 1950.

MR. V. C. HALL, JR. is now associated with the Applied Physics Department of the National Research Corporation, Cambridge, Massachusetts.

MR. GEORGE CLARK, Chairman and Managing Director of the Bryan Donkin Co. Ltd., has retired from these positions. He will remain a Director and will also continue as Chairman of the subsidiary company, British Furnaces, Ltd.

Costing and Modern Accounting Methods in the Metal Industries

Contd. from page 74

In the majority of instances the details entered in the column headed "Particulars of Goods, etc., Supplied" will correspond with those shown under "Description of Requirements," but as, owing to restrictions in supply and other causes, the manufacturer or trader will sometimes arrange with customers for the delivery of goods that differ somewhat from those originally specified, both these columns should be filled in as a matter of routine. All sales transacted on a cash basis should show the number of the page on which the amount of cash received has been recorded in the cash book, but all orders carried through on a credit basis will show the folio on which the customers' accounts appear in the ledger.

Numerous references will have to be made from time to time to the particulars recorded in the order book and consequently it is advisable to simplify the handling of the book. Some pages will contain orders all of which have been fulfilled, and it is a good practice to rule a neat line diagonally across all such pages from corner to corner, care being exercised to ensure that no page is marked off in this way until a number has been entered in either the "Cash Book ref." or the "Ledger Folio" column. This will save a good deal of time and labour and will enable all orders that appear to have been outstanding for an unduly long time to be investigated to avoid any being left only partially fulfilled.

Until such time as the precise requirements or intentions of the buyer have been ascertained or confirmed it is generally unwise to make any definite entry other than a pencilled note of the essential details, and when agents' orders are sent in on ruled forms the particulars

can be copied into the book from the advices and covering letters. Entries representing cancelled orders should be neatly ruled out, and in those cases where the majority of orders are obtained by agents who have been given authority to collect accounts it may be convenient to provide columns for entering the cash records.

Allocation of Costs

While the general charges such as directors' fees, salaries, rent, rates and taxes, insurances, depreciation, upkeep of welfare departments, etc., can sometimes be allocated over the prime costs in accordance with a fixed scale of estimated percentages, the cost of advertising and publicity should be distributed in the light of actual circumstances, as it is often advisable to raise the tempo of orders by emphasising specific qualities in the appropriate trade journals, in which case it is usually not very difficult to ascertain and determine the headings under which the charges should be debited. When all overhead charges are provided for by means of a percentage on prime cost, the rate to be added should correspond as nearly as possible with the ratio which the total of the establishment charges for the last full operating year or other accounting period bears to the total wages paid out plus the cost of the trade purchases for the same period.

The tracking of wastages and leakages, the prompt elimination of unprofitable lines or departments and the remunerative employment of working capital are matters to which every metal manufacturer and trader should give increasing attention, and the next article in the series will indicate methods of controlling stores and metal stocks and will discuss punched card systems and the use of dockets.

LABORATORY METHODS

MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC

INSTRUMENTS AND MATERIALS

DECEMBER, 1949

Vol. XLI No. 242

An Instrument for Routine Polarographic Analysis

By C. H. R. Gentry and D. Newson

One of the main objections to the use of polarographic analysis in the routine laboratory is the time taken in recording the complete polarogram and in making the graphical construction necessary to obtain the diffusion current, which is a measure of the concentration of the metal in solution. The instrument described in this article is designed to measure the diffusion current directly, and is intended specifically for routine metallurgical analysis.

THE general principles of polarographic analysis are well known and need not be repeated here¹. It is only necessary to say that the current-voltage curves obtained with a dropping mercury cathode, under the proper conditions, have two properties of analytical importance: the *half-wave potential*, characteristic of the ion being determined and the *diffusion current* which is directly related to the concentration of the metal in solution. In routine analysis, the half-wave potential is known and the problem is the measurement of the diffusion current.

A large and growing literature exemplifies the application of polarographic analysis in the metallurgical field. However, it would seem that most of this work is a product of research laboratories, and the actual use of polarography, with some important exceptions, in the routine control laboratory is comparatively small. Polarographic procedures have not found the wide practical use, which in the case of the allied spectrochemical and absorptiometric methods has revolutionized analytical control in the metallurgical industry.

In theory, the simplicity of the polarographic method is very attractive; it should be possible to design an instrument in which, after setting the desired half-wave

potential, the diffusion current could be read directly. In practice, it is necessary to obtain the diffusion current by a graphical construction on the current-voltage curve, as shown in Fig. 1. Such curves, known as polarograms, can be obtained from a series of observations made with a manual instrument, or less tediously by automatic recording either photographically or with a pen-recorder on the instrument known as the polarograph. Some very well-designed instruments of this type are available commercially, which admirably fulfil their function of the complete recording of current-voltage curves.

In the works laboratory the recording of the complete polarogram and the graphical construction to obtain the diffusion current—even if simpler methods than that shown in Fig. 1 are used—are to be regarded as time-wasting operations. If an instrument were available which would measure the diffusion current directly, there is little doubt that much of the objection to the routine use of polarography would be overcome. A first attempt at the design of such an instrument, intended specifically for routine metallurgical analysis, forms the subject matter of this article.

Theoretical Considerations

Before it is possible to state the desirable features of the measuring instrument, it is necessary to introduce briefly some of the inherent features of the dropping mercury electrode.

As can be seen from Fig. 1, oscillations exist on the polarogram, which are caused by the growth and eventual severance of each mercury drop. It can be shown theoretically that the diffusion current during the life of each mercury drop is proportional to the one-sixth power of the life of the drop. Since the drop time is normally of the order of 3 sec., galvanometers of very long period are used in conventional

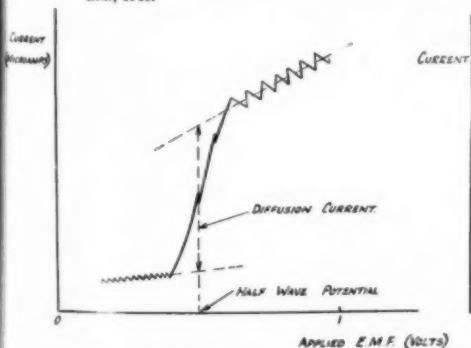


Fig. 1.—Polarogram obtained with recording polarograph.

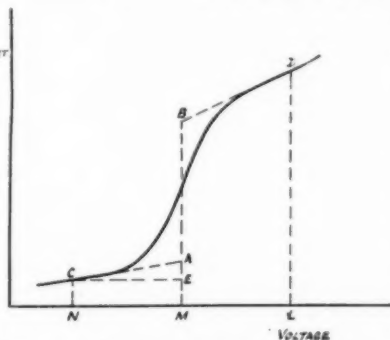


Fig. 2.—Polarogram showing concept of tangent slope.

polarographs with the intention of recording the average current and so overcoming the effect of the drop growth. Various additional methods of damping can also be used, but they often modify the shape of the curves, particularly when small traces are being determined. In the latter case, the effect of severe damping may be such as to disguise completely the existence of a wave. It can be realised that measuring the average current, as is normally done, has inherent disadvantages and it would be preferable to record either the true average current by some electrical method of integration, or to measure the current only at one instant in the life of the drop. The second method has been adopted in the present work, where the current measurement is made only at the instant just prior to the fall of a mercury drop, i.e., at the maximum life of the drop. This choice was originally made because of the much greater experimental difficulties if any other time were used, but it has certain other advantages.

By this means one of the major difficulties in the interpretation of polarographic curves is eliminated for the oscillations due to the growth of each mercury drop disappear. A typical curve (Fig. 2) now consists of two rectilinear portions joined by a steep step of substantially "S" shape, the rectilinear portions being tangential to the ends of the "S" shaped wave. The two straight portions—the residual current line and the limiting current line are, in general, inclined not only to the voltage axis but also to each other. A graphical construction is therefore still necessary to obtain the diffusion current, as given by AB in Fig. 2.

The slopes of the two linear portions of the curve are due in part to the condenser or charging-current, explained by the growth of electrode surface. A circuit is often found in conventional polarographs which can balance out the condenser current by sending a current of suitable size, and proportional to the applied cell voltage, in the opposite direction through the galvanometer. Such a device, known as a residual current compensator simplifies the interpretation of the polarogram, but owing to the different slopes of the two linear portions it does not generally eliminate the need for some graphical construction.

An original feature of the present instrument is a device which has been called a *tangent-slope* compensator which enables the diffusion current to be measured directly, replacing the graphical construction by a simple electrical adjustment. This novel concept will be described in detail later; for the moment, it need only be said that with its aid the recording of the polarogram is no longer necessary in routine work, for the desired measurement may be made manually.

That this is an advantage is apparent from the fact that, in some cases, with the new instrument, the diffusion current can be obtained in less time than was previously required to set the controls on a recording polarograph, prior to the taking of the record.

Requirements of an Instrument for Routine Analysis

On the basis of the considerations which have been discussed and from a general knowledge of the fundamentals of polarographic analysis it is possible to formulate the requirements for an instrument specially designed for routine metallurgical analysis.

These may be enumerated as follows:—

- (1) The measurement of current to a precision under optimum conditions of 0.1%.
- (2) A wide range of current sensitivities to permit a range of concentrations to be determined.
- (3) The measurement of the applied E.M.F. to 0.01 volt.
- (4) Elimination of the effect of current oscillation by measurement of the current only at the instant of maximum life of each drop.
- (5) An electrical method of obtaining the diffusion current directly, without the necessity of graphical construction.
- (6) A compensation device to permit the determination of one metal in the presence of a large concentration of a more easily reduced metal. (This feature has not been incorporated in the present instrument.)
- (7) Robustness, i.e., freedom from interference by vibration, adjacent electrical equipment, etc.
- (8) Ease and speed of operation.

These were the features sought in the present work, and although they were not all completely achieved, the instrument does represent an advance in the right direction.

The Basic Circuit

The basic circuit of the instrument is shown in Fig. 3. In this circuit the potential applied to the analytical cell can be varied by adjustment of the potentiometer R_4 . By including a variable resistance R_1 in the battery circuit and a means of comparing with a standard cell, the total potential drop across R_2 can be fixed at some integral value, so that the applied E.M.F. can be accurately known. To this end the potential divider R_4 is tapped at a point giving a potential drop equal to that of the standard cell, say a Weston cadmium cell, when the correct voltage is being applied across it. By means of a suitable switch, an electronic null point indicator M is used to indicate this condition.

The current passing through the analytical cell is measured by passing it through a load resistor R_3 and measuring the potential drop across this resistor by means of a potentiometer R_5 and the null-point indicator M . The value of R_3 must be large compared with R_4 and R_5 so that the effect of the polarographic current on the voltage distribution along these latter resistances is negligible, but a measurable voltage drop is produced on R_3 compared with the main current. By making the ratio of R_4 to R_5 equal to 10 to 1 and by adjusting R_1 so that 3.3 volts is applied across R_2 , then the E.M.F. applied to the analytical cell can be varied from 3.0 volts in one direction to 0.3 volts in the other. This is the usual range required in polarography.

To use this circuit, after the battery standardisation, R_2 is set at the desired applied E.M.F. and the current is then measured by adjusting R_5 until the null-point indicator shows the null condition. The setting of R_5 then indicates directly the polarographic current. In order to obtain a range of current sensitivities, R_3 is made adjustable in steps.

The purpose of the null-point indicator is to detect the out-of-balance condition, and this is achieved by connecting a condenser alternatively to the two connections shown for the indicator, using a high-speed relay (Carpenter Type 3G) for the purpose. The other side of the condenser is connected to the grid of the first valve of a suitable high-gain amplifier, the output of which is fed to the Y deflector plates of a small cathode-

ray tube (Fig. 4). The X sweep of the latter is synchronised with the relay. By this means a trace is obtained on the screen which represents the relative potentials at the two connections of the null-point indicator as drawn in Fig. 3. As the impedance of the grid circuit is normally high, the trace produced on the screen closely follows the voltage applied to the condenser.

Nature of Trace Obtained

To explain the traces seen on the screen it is convenient to consider what happens when the polarographic

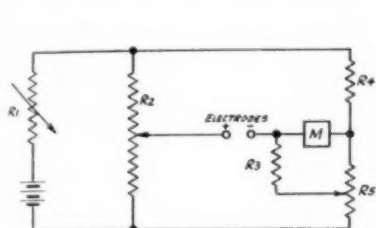


Fig. 3.—Basic circuit.

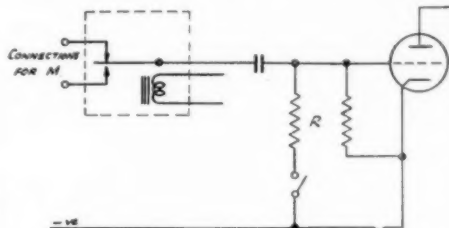


Fig. 4.—Basic circuit for null-point indicator.

cell is replaced by a large resistor. When an E.M.F. is applied to this resistor, a small current will flow which can be balanced out by adjustment of the potentiometer R_5 . Before the balance is obtained the trace consists of two horizontal lines not on the same level. On adjustment of R_5 one line stays stationary in the centre of the picture, while the other moves up or down. Balance is indicated when the two lines meet; the current can then be read from the setting of R_5 .

When measuring a polarographic current the picture is complicated by the fact that the current is no longer constant, but varies with the growth of the mercury drop. The trace therefore, takes the form of one stationary line and one which continuously moves up and down the picture. The movement of this second line enables the growth of the drop to be observed; just prior to the severance of the drop the line moves very slowly because of the sixth power relationship and then suddenly moves back as the drop falls off. Balance is obtained by adjusting R_5 so that the two lines on the screen meet just prior to the severance of the drop. In this way the maximum current is measured, and in practice the adjustment of the current-measuring potentiometer has been found to be very easily carried out. The amplifier gain control on the oscilloscope is used to adjust the sensitivity of the null-point detector at will.

By switching in the low resistance R (Fig. 4), the potential of the grid approximately follows the time derivative of the voltage of the first case. In this way a different form of off-balance trace is obtained on the screen, which some operators find easier to use. This case in use however, is somewhat offset by some loss in sensitivity and the first form of trace is therefore to be preferred.

The Tangent Slope Control

The idea of "tangent slope" control has already been mentioned; it is a means of measuring the diffusion current directly using an electrical method rather than the usual graphical constructions. Before explaining the circuit which makes this possible, it is necessary to explain the operations which are to be made with the circuit.

Referring to Fig. 2, let the potential applied to the cathode be set at a value corresponding to M , the half-wave potential. As this potential is characteristic of a given element, we might say that the instrument has been set for the determination of that element. If now a second control, known as the "potential increment control," is adjusted so that the applied potential is moved to the point N , the current reading on balance will correspond to the ordinate NC , or ME measured along the original ordinate. This is assuming that the tangent slope control is set at zero—i.e., it is

ineffective. At any other setting the latter control adds to the current being measured an amount proportional to the voltage increment, the proportionality factor depending on the setting. If this setting is correct, the extra current will be that represented by EA , and the actual current indicated by the instrument when balanced will be that corresponding to MA .

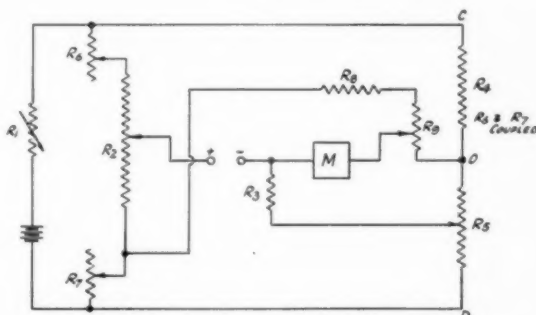


Fig. 5.—Tangent slope circuit, showing the modification of the basic circuit to obtain a reading of the diffusion current.

Thus the normal graphical construction for the point A will have been simulated.

Setting the Control

To obtain the correct setting for the tangent slope control it is necessary only to adjust it until a small change of the potential increment control (say 0.05 V) has no effect on the balance. For then it can be seen that, provided the point C is kept on the linear part of the curves, with the above-mentioned arrangement of controls the same final current is obtained whatever the actual position of C .

The potential increment control is arranged with a central zero position so that it can be varied to take readings also from the other side of M , and thus the point B can be obtained in a similar way. The difference between the two current readings corresponding to B and A gives the required diffusion current. It should be noted that no reading is taken of the tangent slope control position. However, in the final instrument a reference scale has been provided which, it has been found by experience, greatly assists in the measuring procedure.

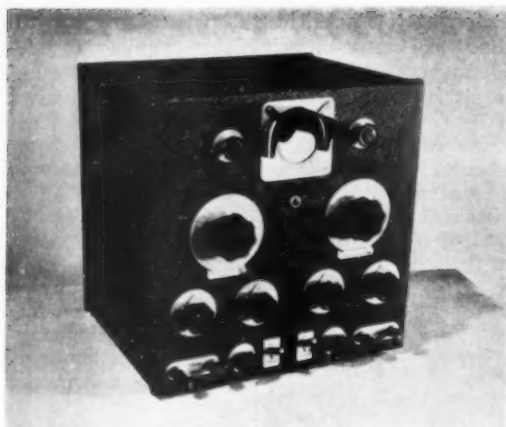


Fig. 6.—The complete instrument.

In order to accomplish this more or less direct reading of the diffusion current, the basic circuit is modified as shown in Fig. 5. The previous potentiometer R_2 has been replaced by three, R_2 , R_6 and R_7 . The latter two are mechanically coupled so that the total resistance in circuit remains constant, and they form the potential increment control. The resistance values are so chosen that with the potential increment control in its central (zero) position, the potential at the lower end of R_2 is the same as at the point O . These two points are connected by a high resistance potential divider, R_8 and R_9 , and from R_9 a small voltage is injected into the null-point indicator. It can be seen that when the instrument is balanced under these conditions the setting of R_5 will differ from previously by an amount corresponding to the voltage obtained from R_9 . Since this is proportional to the displacement of R_7 from its zero position the required conditions described above for measuring the curve have been obtained. R_9 controls the proportionality factor and is therefore the tangent slope control.

The Complete Instrument

On the basis of the principles which have been described the instrument² shown in Fig. 6 has been constructed. This instrument has been in operation for more than a year and has saved considerable time in routine testing.

The polarographic network is shown in Fig. 7 which gives the optimum values for the various components. In this circuit, the current measuring device consists of a potentiometer R_5 connected across two sections of a tapped resistor R_{12} each section of which has half the resistance of the potentiometer. The load resistance R_3 gives nine ranges from $0.6 \mu A$ to $240 \mu A$ current for full scale in the positive direction, the corresponding resistance values being from 200,000 to 500 ohms. The potential divider R_{10} to R_{13} is based on 100 ohms per volt drop and the total working voltage across it is 3.30 volts. The whole network is supplied from a $4\frac{1}{2}$ volt battery contained within the case, the battery switch being coupled with the main switch for the amplifier and cathode ray tube section.

The circuit associated with the null-point indicator need not be described in detail as it may, if necessary,

be replaced by a commercial cathode ray oscilloscope. Care should be taken, however, to earth the various parts of the apparatus well and to screen the circuit for the relay. In the final instrument the complete circuit with three-stage amplifier and cathode ray tube was built in one case.

The controls of the instrument can be seen from Fig. 6. On either side of the cathode ray tube are the focus and brightness controls, which but rarely need adjustment. Below these, on the left, is the main potential control and, on the right, the main current control, each of which has a 4 in. scale moving past fixed cursors. Beneath the main current control is the stepped current switch (the values of these two must be added to give the current readings) and the range switch which gives the multiplying factor for converting dial readings to microamperes. Beneath the potential control are situated the potential increment and tangent slope controls, which are set at zero when not in use. Connections for the standard cell and the polarograph electrode assembly are situated at the bottom of the front panel. Also at the bottom are located the switches, battery standardisation control, and the amplifier gain control, which permits alteration of the sensitivity of the null-point indicator.

As the present instrument is intended to have a current-measuring precision of the order of 1 in 1,000, it is necessary to pay careful attention to the design of the dropping mercury electrode assembly. In particular, it is essential that the temperature of the solutions should be maintained to within $\pm 0.05^\circ C$ and thus a well-designed thermostat is essential. As an anode, it is necessary to use an electrode of known fixed potential such as a saturated calomel or a silver-

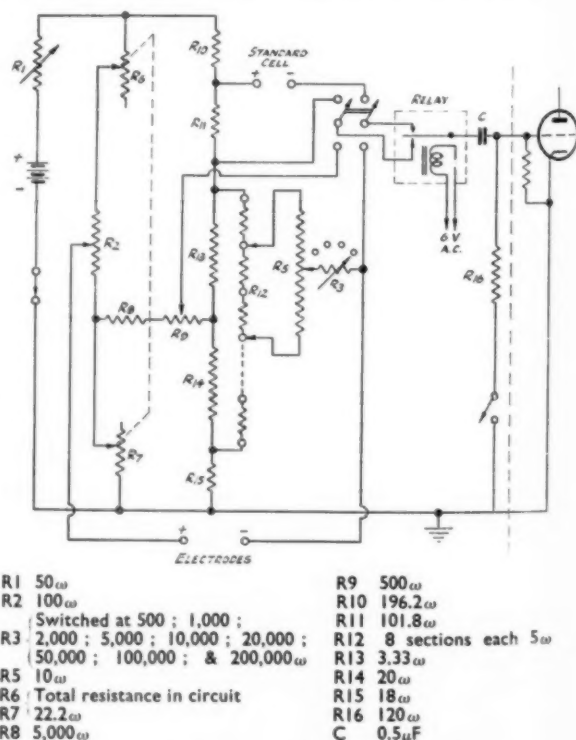


Fig. 7.—The complete polarographic network.

² Some of the novel features of the instrument described have been covered by British Provisional Patent Application No. 9665/48.

silver chloride electrode, rather than the large mercury pool.

For polarographic cells, round-bottomed centrifuge tubes have been found to be convenient to use, easy to clean and cheap to replace. When gassing of the solution is necessary prior to analysis, a stream of nitrogen or hydrogen may be introduced from a simple lead-in tube which is readily removed and replaced by the dropping electrode and dip-type anode assembly. Provision for gassing a batch of solutions simultaneously is an essential feature when the apparatus is to be used in a routine laboratory.

Applications

The present instrument is intended to be used for the routine determination of constituents of materials of known types. It can be assumed therefore, that the half-wave potential of the element to be determined and the general shape of the polarogram are known. If not, the complete polarogram of a typical solution must be plotted manually or registered on a photographic- or pen-recording polarograph. The subsequent routine procedure depends on the shape of the polarogram. If the residual current and limiting current lines are parallel, it is simply necessary to read the current at each of two fixed potentials, one just prior to and the other just after the polarographic wave. If, however, the polarogram has the shape of Fig. 2, it is necessary to use the tangent slope control.

As examples of the type of determinations which have been made with the present instrument we may mention lead or pickel in steels; lead in brasses;

cadmium in copper; cadmium, zinc and bismuth in silver solders; the main metal in plating baths, etc.

The precision attainable is such that in the case of, say, nickel in permanent magnet alloys, or cadmium in silver solders, duplicate results are normally obtained to within 1 in 300.

The present instrument is obviously ideally suitable for amperometric titrations, although the authors have not employed it for this purpose on a routine basis. It has however found a use, on occasions, for potentiometric titrations of chromium or manganese in steels, when the usual titrimeter has not been available. In these cases the current dials are set at zero and balance found by adjustment of the potential dial. It is possible in this manner to make many of the titrations commonly required in metallurgical analysis. This may be an advantage in smaller laboratories where the scope for potentiometric titrations and polarographic analysis is not sufficiently great to warrant the purchase or construction of two instruments.

In conclusion, it may be said that an instrument has been constructed which has many of the desirable features required for work in the routine metallurgical laboratory. It is to be regarded as a first approach to the ideal industrial instrument in which the operator merely sets one control to the half-wave potential and then reads off the diffusion current directly.

Acknowledgment

The authors wish to thank Mr. J. A. M. van Moll and the Directors of Philips Electrical Ltd. for permission to publish this paper.

Primary Analytical Standards

By A. J. Nutten

Department of Chemistry, The University, Birmingham

The accurate standardisation of volumetric solutions is of great importance whether an analysis be conducted on the macro or micro scale. In the latter case, however, the problem of achieving the standardisation satisfactorily can be aggravated. Because of the much smaller masses involved, not only purity needs to be considered, but the equivalent weight of the standard assumes a greater significance. This article forms the first instalment of a systematic review of the various substances which have been advanced as primary standards.

THE requirements that should be met by a primary standard have been listed by Dodge¹. They are as follows:—

1. The standard should be easily obtained in a state of purity.
2. It should be unalterable in the air at ordinary or moderately high temperatures.
3. It should have a high equivalent weight, thus lessening the effect of small errors in weighing.
4. It should be readily soluble in water and ethanol, thus allowing immediate titration in the cold.
5. On titration, no interfering product, such as carbon dioxide should be present.
6. The standard should be free from colour, before and after titration, to avoid interference with indicators.

It is proposed in this review to deal with most of the substances which have been advanced as primary standards. Their advantages and disadvantages will be

discussed, bearing in mind the requirements listed by Dodge. For purposes of reference the substances to be described have been grouped into three classes:—

I.—Alkalimetric and Acidimetric.

II.—Oxidimetric.

III.—Argentometric.

For convenience, the most suitable indicator to use is listed where possible, but, obviously, any other good indicator working in the same pH range may be substituted. The object of listing them is to emphasise in some cases the necessity for selecting the proper indicator, e.g., in the case of the weak acid standards.

I.—ALKALIMETRIC AND ACIDIMETRIC

Potassium Biphthalate

$C_8H_4(COOH)(COOK)$. Eq. Wt. 204.22. Weak Acid.
Indicator: Phenolphthalein.

Dodge¹ recommended potassium biphthalate as a primary standard for alkali standardisation. It con-

forms to all six requirements of a primary standard and is soluble in 10 to 11 parts water at ordinary temperatures and in about 400 parts ethanol.

The salt is prepared as follows: 50 g. resublimed phthalic anhydride are dissolved in 200 ml. water and the solution exactly neutralised with about 60 g. pure potassium hydroxide in an equal amount of water. 50 g. phthalic anhydride are added and the mixture warmed till all crystals are dissolved. The solution is made up to 550 g. with water, filtered hot, and cooled with continuous agitation to promote formation of small crystals. The product is filtered by suction, recrystallised from 300 ml. hot water, and dried at 110° C.

In a later paper, Dodge² mentions that recrystallisation at temperatures above 20° C. entirely eliminates the possibility of contamination by the more acid triphthalate, $2\text{KHC}_8\text{H}_4\text{O}_4 \cdot \text{C}_8\text{H}_6\text{O}_4$.

Hoffmann³ found that standard aqueous solutions of potassium biphthalate do not vary in strength over a period of one year under average laboratory conditions. Direct sunlight had no effect on the solution.

Hendrixon⁴ stated that three recrystallisations are sufficient in the preparation of the salt, that the product is of constant composition, and that its hygroscopicity is almost nil.

Potassium biphthalate is obtainable commercially in a sufficiently pure state for standardisation purposes, and from the above and numerous other observations it may be concluded that the substance is an acceptable primary standard.

Benzoic Acid

$\text{C}_6\text{H}_5\text{COOH}$. Eq. Wt. 122.12. Weak Acid.
Indicator: Phenolphthalein.

Benzoic acid has been recommended by Morey⁵ as a primary alkalimetric standard. He prepared the pure acid as follows: C.P. material was recrystallised twice from ethanol and once from water, followed by fractional sublimation *in vacuo*. The sublimed acid, because of its bulk was, before weighing, fused in a covered platinum dish placed in an oven heated to about 140° C. When melted, the liquid was poured into a test-tube to solidify. The solid stick obtained was broken into pieces of convenient size, and preserved in a glass-stoppered bottle. This fusion process diminishes the possibility of large surface effects. Samples so prepared, Morey states, can be kept indefinitely and used without preliminary drying.

The experiments of Weaver⁶ indicate that benzoic acid is slightly hygroscopic. A sample of the acid, purified by Morey, was shown to have taken up 0.07% water during a 12-month period. Weaver recommends that fusion to remove moisture be carried out at as low a temperature as possible. After fusion the acid should be perfectly colourless.

MacInnes and Cowperthwaite⁷ state that, although difficult to get into aqueous solution, benzoic acid is unquestionably an excellent substance for use in precise alkalimetry. Using an electrometric method they found that benzoic acid was suitable for accurate work (0.01% or better).

The one objection to benzoic acid as a standard substance is its sparing solubility in water at ordinary temperatures.

Furoic Acid

$\text{C}_6\text{H}_5\text{O.CO.OH}$. Eq. Wt. 112.08. Weak Acid.
Indicator: Phenolphthalein.

Furoic acid was proposed as a standard substance by Kellogg and Kellogg⁸. The acid was prepared from the

technical material by recrystallisation from water, followed by 2 sublimations. Furoic acid, prepared in this manner, was exposed to average laboratory conditions for a period of three months. A gain of 0.04% was reported in that time indicating very slight hygroscopicity, but this trace of moisture was easily removed by careful fusion.

Before use, the purified acid was fused in a covered platinum dish over an air-bath, the temperature not exceeding 142° C. The acid was cooled in a desiccator.

The normalities of a sodium hydroxide solution, determined with potassium biphthalate, benzoic acid and furoic acid, agreed closely in all cases showing that furoic acid, prepared as above, has a purity of 100% and possesses a neutralising power almost equivalent to that of benzoic acid. Its greater solubility in water gives it a distinct advantage over the aromatic acid as a primary alkalimetric standard.

Potassium Biiodate

$\text{KH}(\text{IO}_3)_2$. Eq. Wt. 389.94. Strong Acid.
Indicator: Phenolphthalein/Methyl Red.

Kolthoff and van Berk⁹ prepared potassium biiodate by the method of Shaffer and Hartmann¹⁰, whereby potassium chlorate, concentrated hydrochloric acid and powdered iodine are heated together and the solution filtered, giving, when cooled, crystals of potassium biiodate which are recrystallised from water and dried.

Several workers advocate the use of the 2nd or 3rd recrystallisations to ensure complete purity. For the recrystallisation, one part of the salt is dissolved in three parts of water, and the mixture cooled with continuous stirring. The crystals are dried at 120° C., but no higher.

The high equivalent weight of potassium biiodate renders it particularly suitable for standardisation of alkali; furthermore, the iodic acid behaves as a very strong acid.

Butler, Smith and Audrieth¹¹ list some of the properties of potassium biiodate. They state that the salt, being strongly acidic, is capable of use in connection with a group of indicators having transition points over a wide range of pH values (pH 5-9). They point out, however, that three recrystallisations are necessary to attain satisfactory purity, that the salt is relatively expensive due to its high iodine content, and that it possesses such a low solubility in water at ordinary temperatures that it is difficult to prepare solutions over 0.1M.

It is not possible to obtain commercially in this country potassium biiodate of a purity suitable for direct use. The commercial product must be recrystallised three times before use.

The salt is used extensively as a standard in alkalimetry.

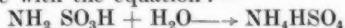
Sulphamic Acid (Amino-Sulphonic Acid)

$\text{NH}_2\text{SO}_3\text{H}$. Eq. Wt. 97.09. Strong Acid.
Indicator: Phenolphthalein/Methyl Red.

Misuch¹² states that sulphamic acid and hydrochloric acid give identical results when titrated with sodium hydroxide, carbonate and borate.

Experiments are described by Herboth¹³ indicating the ease of preparation of sulphamic acid, its exceptional keeping properties when exposed to atmospheric conditions, and its reasonable accuracy when used as a standard in connection with the indicators dimethylaminoazobenzene, methyl red, phenolphthalein and rosolic acid.

Much work on the use of sulphamic acid as a standard of reference has been carried out by Butler, Smith and Audieth¹¹. It is a crystalline solid, non-hygroscopic, and melting (with decomposition) at 205° C. It is highly ionised in aqueous solution and is stable indefinitely in the solid state at ordinary temperatures, though undergoing slow hydrolysis in solution in accordance with the equation:—



The acid is fairly soluble in water (14.68g./100g. at 0°) and, according to Butler *et alia*, may be favourably compared with such existing standards as benzoic acid, potassium biphthalate and potassium biiodate.

Properly purified, sulphamic acid is stated to have a definite known hydrogen ion concentration, purification being easily accomplished by a single recrystallisation from water. The material is cheap, and can be used with an indicator range *pH* 4–9. Butler *et alia* obtained slightly low results compared with constant-boiling hydrochloric acid, this probably being due to a very small trace of occluded moisture.

Kolthoff¹⁴ states that, as no purity tests for sulphamic acid are to be found in the literature, the substance is not to be recommended as a primary standard, although it may be useful as a secondary standard. On the other hand, Belcher¹⁵ has obtained very satisfactory results in the titration of alkali with a commercial specimen of sulphamic acid, and thoroughly recommends its use as a primary alkalimetric standard.

Constant-Boiling Hydrochloric Acid

Strong Acid.

Indicator: Phenolphthalein/Methyl Red.

The use of constant-boiling hydrochloric acid as a standard in volumetric analysis was first suggested by Hulett and Bonner¹⁶ who found that it has a definite composition, is obtained easily, and from it a standard solution of hydrochloric acid may be directly, easily, and accurately prepared. Whether strong or weak hydrochloric is used in the still, the acid, when distilled, will approach a point where it distils over unchanged in composition, the residue at this point having the same composition as the distillate. The composition of the constant-boiling acid varies with the pressure to a small extent, but only for the most accurate work need one consider the pressure under which the acid is distilled, if the barometer is in the vicinity of 760 mm.

By starting with hydrochloric acid of *d* = 1.10, made up using an ordinary hydrometer, and distilling off three-quarters of the liquid taken, the above workers found that the distillate following had a density of 1.09620 at 760 mm. and contained 20.242% hydrogen chloride. A molecular weight of silver chloride requires 180.17 g. (air weight) of the constant-boiling acid, and this weight of the acid contains 1 mole (36.47 g.) hydrogen chloride (or 20.240%). A normal solution of the acid thus weighs 180.170 g. and this can be weighed to less than 10 mg. The constant-boiling acid, according to Hulett and Bonner, is not hygroscopic or noticeably volatile.

Foulk and Hollingsworth¹⁷ showed that the percentage of hydrogen chloride in the constant-boiling mixture diminishes as the rate of distillation increases, but the effect is negligibly small. They state the most probable value of the composition of the constant-boiling mixture as follows: "If the distillation is made at a pressure

of 750 mm. from a flask (described in the paper) and at the rate of 3–4 ml. per minute, the constant-boiling mixture contains 20.245% hydrogen chloride." They compare their own with previous work by Hulett and Bonner¹⁶, Morey⁵ and Hendrixon¹⁸. These workers omitted some of the usual corrections employed in precise work, viz.: (i) for vacuum weight of the mixture, (ii) for vacuum weight of silver chloride, (iii) for silver chloride in the washings, and (iv) for water lost by fusion of the silver chloride. By making the necessary corrections in the results of these workers, Foulk and Hollingsworth found that, in terms of the percentage of hydrogen chloride in the constant-boiling mixture distilled at 750 mm. pressure, the corrected results were as follows:—

	% HCl
Hulett and Bonner	20.258
Morey	20.252
Hendrixon	20.253
Foulk and Hollingsworth	20.245

The agreement amongst these four independent results is remarkable, and should tend to place this constant-boiling mixture on a firm basis as an analytical standard.

Using a differential potentiometric method, MacInnes and Dole¹⁹ obtained a value of 20.248% for the composition of the constant-boiling acid, and this value, in close agreement to that of Foulk and Hollingsworth may be accepted as the true value. It would be useful if constant-boiling hydrochloric acid were available commercially.

Perchloric Acid

HClO₄. 2H₂O. Strong Acid.

Indicator: Phenolphthalein/Methyl Red.

Smith and Koch²⁰ in advocating perchloric acid as an alkalimetric standard, describe a process for the preparation of the acid by vacuum distillation. The product corresponds most closely with the dihydrate HClO₄. 2H₂O, theory 73.6% HClO₄. The conditions of the preparation are shown to be easily duplicated. The process consists of distilling perchloric acid of 72% strength in a properly designed still at 2–7 mm. pressure until half the product has been fractionated. Distillation is then interrupted, and the distillate discarded. The residue is then distilled under the same conditions to obtain the standard product.

The rate of distillation is of no consequence. According to Smith and Koch, perchloric acid of this standard strength is slightly hygroscopic and fumes very faintly. It should be weighed with the usual precautions to prevent absorption of atmospheric moisture. For the preparation of a 1N solution of perchloric acid 136.4201 g. of the above product is weighed off and diluted to 1,000 ml. with water.

The above workers state that the preparation of standard perchloric acid compares more than favourably with that of constant-boiling hydrochloric acid. Thus the pressure of distillation must be known in the case of the hydrochloric acid and a barometer is required. With perchloric acid the pressure may vary over the range 2–7 mm. and the use of the barometer is eliminated. The preparation of the hydrochloric acid must be carefully controlled as regards rate of distillation, bumping, etc.

1 ml. of 73.60% perchloric acid equals 2 ml. of constant-boiling hydrochloric acid in equivalents of acid

contained. Since perchloric acid can be distilled twice as fast, and since 50% of the starting product is obtained compared with 25% for the hydrochloric acid, the yield of perchloric acid obtained in a given time, as compared to hydrochloric acid, may be eight times as large. Perchloric acid is thus a convenient standard for use in alkalimetry.

(to be continued).

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A Flowmeter Suitable for Measuring Wide Ranges of Flow-rate

By R. BELCHER and G. INGRAM

ONE of the best types of flowmeter for measuring variable rates of flow is that designed by White and Wright,¹ the orifice consisting of the annular space between a glass rod inserted inside a glass tube. By varying the length to which the rod is inserted into the tube and by using narrower or wider rods, a wide range of flow-rates can be measured conveniently. Although the apparatus has given satisfaction over a period of years, it has one minor drawback. When very small rates of flow have to be measured a tight-fitting glass rod must be used to obtain sufficient restriction in the orifice to give a measurable deflection in the manometer. Not only is it often difficult to obtain glass rod of the requisite diameter, but the insertion of such a tight-fitting rod often fractures the ring seal by which the glass tube is attached inside the apparatus. This has led us to design a flowmeter which is more robust and easier to construct, whilst retaining the great flexibility of the White-Wright flowmeter.

In order to measure a wide range of flow-rates, the older method of using a capillary orifice has been adopted. The use of such a series of capillaries of different bore would entail some practical difficulty, for a large stock of capillary tubing would have to be examined to select the desired lengths and each individual piece would require testing to prove its suitability prior to calibration. The labour involved may, however, be reduced considerably by using varying lengths of the same capillary. Thus, if one particular section of the tubing is found suitable for a particular range, further ranges both above and below, may be measured by using shorter or longer pieces of the same tubing, providing the bore is reasonably uniform. Although each piece will require calibrating, a rough idea of the range it will cover may be obtained by simple calculation.

Although the longest piece of capillary which may be inserted is about 6.5 in. in length, the overall height and width of the flowmeter is less than that of the White-Wright apparatus. This is achieved by using the whole of the body of the flowmeter to contain the longest capillary required.

Two alternative designs are illustrated in the accompanying diagrams. In Fig. 1, the flowmeter is constructed in one piece, the manometer tube being filled by means of a pipette. In Fig. 2, the manometer tube is attached by two small ground glass joints to facilitate its filling with the flowmeter liquid. These joints may be cemented in place by Krönig cement or, as we have found to be perfectly satisfactory, they may be treated

with tap-grease and held in position by a sliding block, suitably notched so that the bend of the manometer tube fits into it, and attached to the flowmeter stand.

The overall height of the flowmeter is about 7 in., the wide tubing used for the body is about 0.5 in. in diameter and the manometer tubing is about $\frac{1}{8}$ in. external diameter.

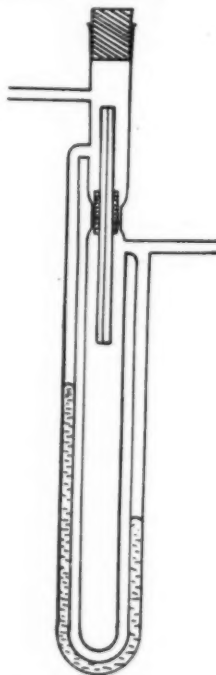


Fig. 1.—Flowmeter constructed in one piece.

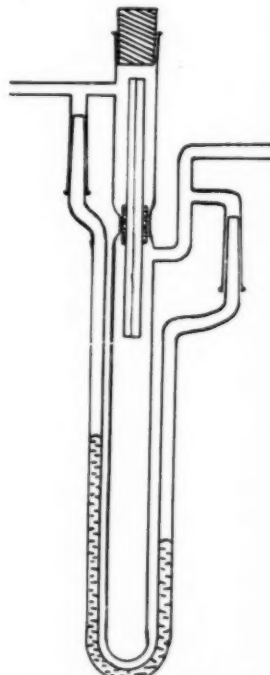


Fig. 2.—Flowmeter with detachable manometer.

A piece of capillary tubing as long as possible should be selected and calibrated. Further pieces should then be cut from the same length of stock tubing, differing by 1 in. (or less if desired) down to 1 in. in size, and calibrated. The process is then repeated with capillary tubing of larger and smaller bore until the ranges required are completely covered.

When a suitable range of capillaries has been selected and calibrated they should be stored with the small rubber bungs used for fixing them in position still attached. The bung should be moistened before being inserted and pressed firmly into position with a pair of blunt-ended forceps. The same forceps should be used to remove the capillary by gripping the upper surface of the bung, releasing it by a slight rocking motion and then pulling it out gently.

¹ White and Wright. *Can. J. Research*, 1936, **14B**, 427.

Metallurgical Applications of the Electron Microscope

Report on Recent Symposium

By G. A. Geach, Ph.D., F.I.M.

In the early stages of the development of a new technique, it is natural that considerable attention should be devoted to the perfection of the equipment used and to a study of its potentialities. There is always the danger that this may come to be regarded as an end in itself and, consequently, a useful purpose was served by the recent symposium on The Metallurgical Applications of the Electron Microscope in drawing attention to the type of problem to which the instrument has been applied as well as to the special techniques involved in metallographic work.

ELECTRON metallography, until recently an unfamiliar and difficult technique, is now becoming accepted as a normal procedure in metallurgical research. In the past, gatherings devoted to electron microscopy have been for specialists concerned with the development of the instrument and associated techniques, but the Symposium on Metallurgical Applications of the Electron Microscope, organised by the Institute of Metals and seven other Societies, which was held in London during November, made clear the change in attitude. About two hundred people were present at the Royal Institution, and although this number included several visitors from the Continent, it nevertheless represents five or six workers for every electron microscope in this country.

Such a Symposium serves two valuable ends. In the first place it collects together workers in a subject and provides them with an opportunity to clarify ideas and exchange important little items of information which are often left out of formal publications. On the other hand it provides for the "lay body" a general impression of the state of the subject. In the present case this is most important, for even those metallurgists with the least expectation of themselves making use of the electron microscope are likely soon to encounter its results in their own fields and so to need sufficient familiarity with the subject to interpret and evaluate the new observations. An exhibition of metallurgical electron micrographs by several workers was also arranged, and after the formal discussions simple replica techniques were demonstrated to small groups. A Metropolitan-Vickers EM-3 microscope and a Philips'

microscope were on show. A full report of the Symposium will be published later by the Institute of Metals: in the meanwhile this short account is written for the general metallurgist.

The papers discussed at the Symposium could be divided almost evenly into three groups. One consisted of reviews of the subject from different points of view,

usually of the work carried out in the author's home country; these papers were of a type now rather familiar, although Dr. Allen's more general review was an advance on many papers of this type in its critical consideration of the metallurgical, as distinct from the instrumental, aspect. Another group dealt mainly with developments of technique, and a third presented metallurgical studies in which the electron microscope had been used and was even essential, but in which the primary concern was a metallurgical problem. In fact, as Professor Finch pointed out, the proper attitude to such a problem would not lead to a paper with a title stating specifically that an electron microscope had been used. In the past there has been a tendency for the man working with an electron microscope to be primarily interested in his complex instrument and the techniques associated with it, and only to a lesser extent in the background of the

problem to which he is applying them. This state of affairs, bringing into existence a class of "electron microscopists," was criticised by Professor Finch who categorically stated this to be a thoroughly bad term; the fact that the electron microscope was used in an investigation should be a very minor matter in any presentation of the work, the important

LIST OF PAPERS PRESENTED AT THE SYMPOSIUM

- The Application of the Electron Microscope in Metallography.** (Introductory Paper), by N. P. Allen (N.P.L.)
- The Structure of Some Non-ferrous Alloys as revealed by the Electron Microscope,** by G. L. J. Bailey and S. Vernon-Smith (B.N.F.M.R.A.)
- Elementary Slip Processes in Aluminium as Shown by the Electron Microscope,** by A. F. Brown (Cavendish Laboratory.)
- Observations on the Age-hardening Process in an Aluminium-Copper Alloy,** by G. L. Bucknell and G. A. Geach (A.E.I. Research Laboratory.)
- Studies in the Electron Microscopy of Nickel-Chromium Alloys,** by B. S. Cooper and G. A. Bassett (G.E.C.)
- Electron Microscopy in Metallurgy,** by Professor P. Grivet (Sorbonne, Paris.)
- Electron Microscopy of Light Metal Alloys,** by F. Keller (Aluminium Company of America.)
- The Use of the Electron Microscope in Metallurgical Research in Germany during and since the War,** by H. Mahl (Süddeutsche Laboratorien G.m.b.H.)
- A Note on the Examination of Metal Powders by the Electron Microscope,** by J. I. Morley (Firth-Brown Research Laboratories.)
- A Replica Technique for the Examination of Fracture Surfaces with the Electron Microscope,** by J. Nutting (B.I.S.R.A.) and V. E. Cosslett (Cavendish Laboratory.)
- The Dry Stripping of Formvar Replicas from Etched Metal Surfaces,** by J. Nutting (B.I.S.R.A.) and V. E. Cosslett (Cavendish Laboratory.)
- The Microstructure of a Water-quenched Carburized Iron,** by J. Trotter, D. McLean and C. J. B. Clews (N.P.L.)
- The Progress of Electron Microscopy of Metals in America (excluding the Light Metals),** by C. M. Schwartz (Battelle Memorial Institute.)

factors being the problem and the results. There is a great temptation for the microscope to dictate the direction in which a research is made rather than for a problem to dictate the application of an electron microscope. One international authority on the electron microscope has estimated that perhaps only 2% of the microscopes known to him are producing results of fundamental importance in branches of science other than electron optics itself.

Interpretation

In metallurgy the results of electron microscopy have, in the past, been met with considerable scepticism and, as Mr. G. L. Bailey pointed out, this is still at times true. It is difficult when one is presented with a completely unfamiliar picture, and told that it represents some perfectly familiar structure at a magnification of an order higher than is customary, to accept the result; it requires considerable training or a real mental effort to appreciate, in terms of the technique for obtaining electron micrographs, the physical form of the surface under study. This is all the more true in that it is shown that artefacts can be introduced by the replica techniques used in metallography. Dr. Cosslett said that metallurgical specimens are more difficult to interpret than biological ones in which it is not often possible to extrapolate from previous work at lower magnifications, and in which, consequently, there is not the difficulty of attempting to fit the new results into the old mental picture. He was of the opinion that specialists in "electron microscopy," flushed by great and easy success

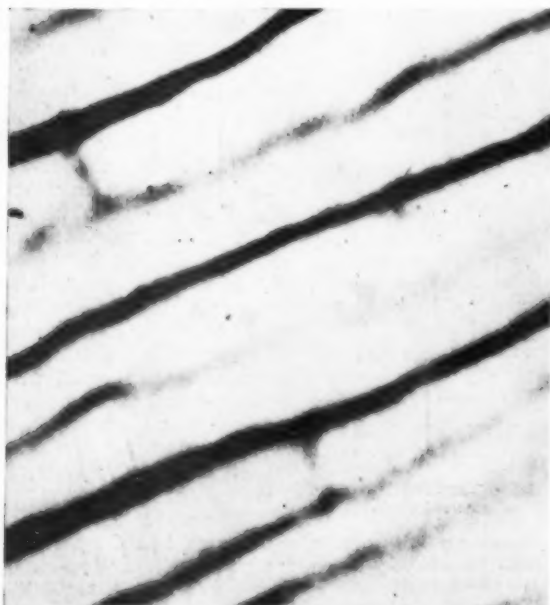
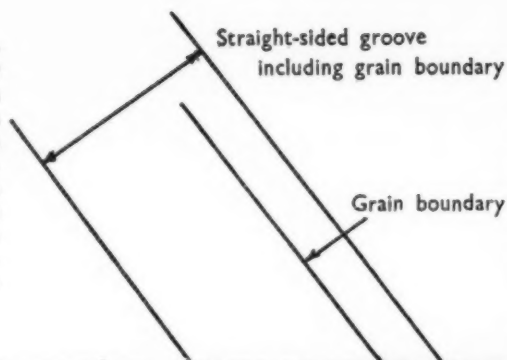


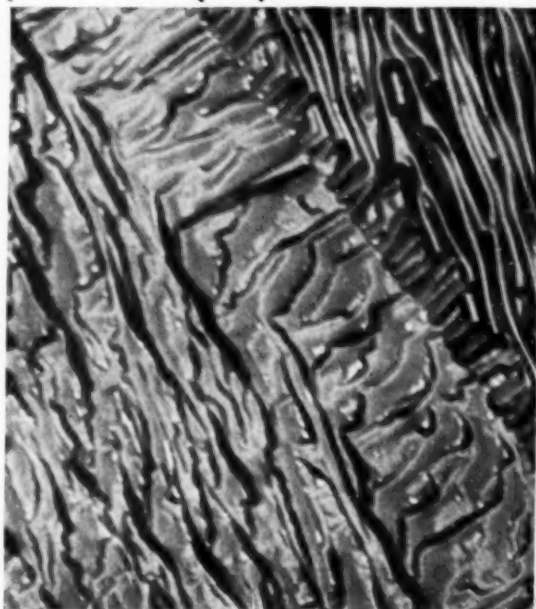
Photo due to Dr. J. Nutting.

A replica of pearlite prepared by impressing the surface on to aluminium, anodising this and removing the oxide film as a replica. The dark lines represent steep slopes in the contour of the pearlite surface, that is the edges of the cementite. Small cross linkages presumably represent steps in the ferrite. The relative widths of the ferrite and cementite lamellae are anomalous.



An aluminium alloy showing a typical "crystallographic etch" structure: in this case the surface resembles the cross-fracture through a pile of crumbly plates. The groove at the boundary between differently oriented grains can be seen. Aluminium-oxide replica.

Photo due to Mr. G. L. Bucknell and Dr. G. A. Geach.



in biological work, were somewhat nonplussed by the difficulties that metallography was presenting to them.

Another important difficulty in the interpretation of electron micrographs often arises from the fact that the field examined is minute and can very rarely be considered typical of the whole range of structures on the surface of a specimen. In consequence, comparison of a small number of fields of different specimens might lead to completely erroneous deductions about their relative structures.

An example of the difficulty in interpretation arose with Dr. Hume-Rothery's question, why the apparent proportions of ferrite and carbide in electron micrographs of pearlite in eutectoid steels should be so far from the correct ratio of about seven to one. This is often true when plastic replicas are used and is also very marked on a micrograph taken by Dr. Nutting using the aluminium-impressing technique. A similar phenomenon in optical metallography can be explained by the revelation of extra cementite as a result of the erosion of ferrite on etching. The same explanation seems less directly applicable to replicas and, although a good deal of discussion of this matter occurred, no satisfactory explanation was presented at the meeting.

Crystallographic Etch

Another type of structure which aroused considerable critical comment was the "crystallographic etch" or

fragmented surface found, for example, in studies of nickel-chromium alloys described in a paper by Messrs. Cooper and Bassett. Similar structures have been described frequently: in the exhibition of prints Professor Coheur had one of an etched chrome-molybdenum steel whose surface was broken up into minute fragments about 1 micron across. Mr. Bailey, who disliked this type of picture, suggested that the only deduction to be made from it must be that the etchant used was wrongly chosen. It is undoubtedly true that the extra factor of ten or more in the magnification of the electron micrograph is going to present the metallographer with enormous problems in the development of etching techniques. Methods which in the past have served satisfactorily to differentiate constituents

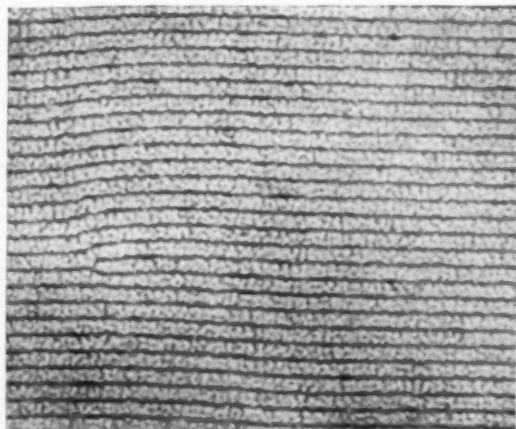


Photo due to Mr. G. L. Bucknell and Dr. G. A. Geach

Oxide replica of pure aluminium showing the "micro-etch" structure in the form of furrows which are probably traces of (100) planes. The spacing in the plane of the specimen is about 1,800 Å.

and bring out grain boundaries are, in electron micrographs, presenting confused toothed or torn structures in which little of significance can be grasped. On the other hand, as Barrett has pointed out, the very nature of these etched surfaces may itself be important for studies of crystal texture and mosaic structures. Closely related structures commonly observed are ridges or steps in the surface and these patterns appear frequently to be related to the crystal symmetry of the specimen.

Dr. Smith suggested that these "crystallographic etch" structures may be similar in nature to the thermal etching patterns observed on silver by Chalmers, King and Shuttleworth, although the scale of magnitude of the thermal etch patterns is, of course, much greater. The two effects do resemble each other very markedly in all other respects. It is interesting to recall in this connection the relationship of thermal etch patterns to crystal symmetry: here the ridges and steps are made up of little areas of (100) or (111) planes, those of lowest free energy, and when the angle between one of these planes and the surface of the specimen is small the pattern does not develop.

Dr. Brown gave attention to the "orange peel" structure sometimes observed on aluminium-oxide replicas. Although he was unable to observe this, unless the replica had been shadowed, Mr. Bucknell and Dr. Geach had photographs in the exhibition of a more

marked structure, often in the form of furrows about 600-1,000 Å wide and clearly observed without any shadowing. This linear structure has a definite relationship with the underlying crystal lattice and can be interpreted as the traces of (100) planes. A recognisable "orange-peel" structure on a Formvar replica of an iron specimen was shown by Dr. Challice and, in the exhibition of prints, one by Professor Coheur showed slip lines in a chromium-molybdenum steel with quite a distinct pattern of furrows almost perpendicular to the slip lines: in this case the spacing of the lines was also about 800 Å.

Relevant to this was a study reported by Dr. Keller and carried out in America. Whereas an anodic film formed in an electrolyte in which it is insoluble is structureless at a magnification of 60,000 diameters, the thicker film formed in an electrolyte in which it can dissolve contains pores. A replica of a section taken through such a film showed, at a magnification of 35,000, these pores widening as they approached the free surface, work confirming that published recently by Huber in Switzerland.

Precipitation

Dr. Allen outlined the more important problems to which electron metallography should make worth-while contributions. He included the study of grain-boundary films and of small insoluble particle in metals (which may be of the utmost importance in such processes as the modification of aluminium-silicon alloys), the grain refinement of magnesium-casting alloys, and the effect of boron on the hardenability of steels. Larger problems included the study of the precipitates formed in age-hardening alloys in general and of those constituents

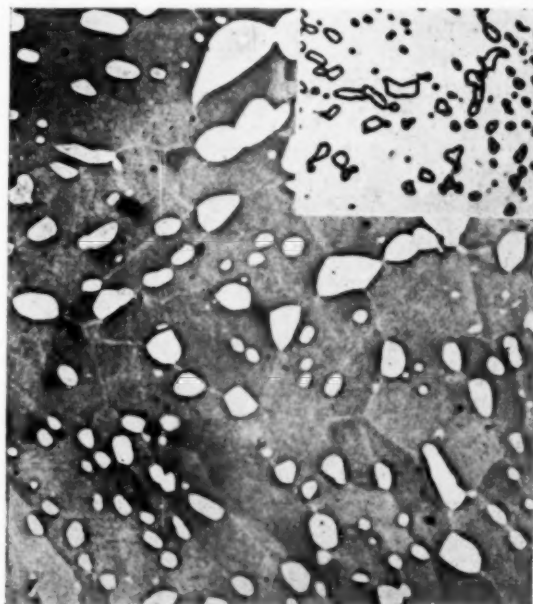


Photo due to Trotter and McLean, J.I.S.I., 1949

A 0.6% carbon steel quenched and tempered at 700°C. Dark bands probably introduced by the form of the Formvar replica appear around the large carbide particles. Thin films or ridges, probably of impurity rejected as the ferrite grew from austenite are also visible. Magnification 5,000. (Inset, optical micrograph $\times 2,000$).



Photo due to Mr. G. L. Bucknell and Dr. G. A. Geach.

Plates of precipitate in an aluminium-copper alloy showing how these apparently form by the congregation of small particles on a common plane. Aluminium oxide replica. Magnification $\times 16,000$.

of hardened and tempered steels usually covered by such terms as sorbite, troostite, bainite and martensite. He indicated some correlation between modern theories of hardening (Orowan, Nabarro and Bragg) and the particle size and particle spacing in tempered medium-carbon steels.

From the National Physical Laboratory a study of the structures observed in quenched plain-carbon steels of various carbon contents was reported. The samples, prepared by carburising Swedish iron, were quenched and etched in 1% alcoholic nitric acid and studied by means of unshadowed Formvar replicas.

A number of undoubtedly important results are emerging from this work. A 0.2% carbon steel consisted of ferrite with isolated particles of carbide, together with certain thin films appearing as ridges which, it is suggested, are similar to films observed by Carpenter and Robertson, and which are attributed to impurities rejected as the ferrite grows from austenite. Suggestions that these ridges might be artefacts, of the type observed around particles or steps in a structure, seem to have been disposed of by Mr. McLean, who pointed out that they have been observed after etching in picric acid and also by phase-contrast microscopy. In specimens aged from two to five weeks, mottling of the ferrite background suggests incipient precipitation. In a 0.4% carbon steel the structure consisted of martensite between plates of ferrite often with ridges at the boundary. Troostite was shown to consist of small parallel plates in a matrix of ferrite.

Other photographs confirm the initial decomposition of martensite to the granular structure already described by Mahl and by Semmler-Alter. These decomposed areas are those which etch to dark needles when observed optically; undecomposed martensite gives the light needles. There is less evidence of this decomposition as the carbon content increases.

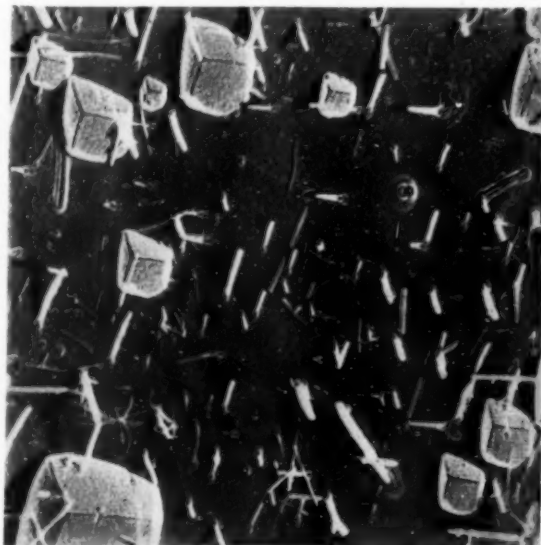
Observations on the ageing of a 0.7% carbon steel at room temperature are very interesting. After seven weeks, precipitate can be detected in the background, although nothing can be seen optically. Precipitate which is just visible in the light microscope appears after ageing at 250° C. for 1 hour: electron micrographs

show this to be in the form of platelets. These do not occur in the immediate vicinity of large particles of carbide.

This interesting work suggests comparison with that of Heidenreich who, by electron microscopy and electron diffraction methods, showed the first precipitate in tempered martensite to be isomorphous with iron nitride. Trotter and McLean have already published observations showing that a fine precipitate occurs on tempering at 170° C., discrete platelets at 200° C. and, at 700° C., rounded particles. X-ray diffraction study of iodine residues from steels has confirmed that, after tempering at approximately 250° C., a hexagonal structure is present together with thin plates of cementite.

In his review of American work Dr. Keller gave a table of the particle size of precipitates in a number of aluminium alloys which had been aged to give maximum hardness or strength. This size is totally different for different materials, ranging from 0.02 microns in aluminium-magnesium to 0.5 microns in aluminium-silver. It appears, therefore, that the size for a "critical dispersion" differs from case to case, and Dr. Keller suggests that an important factor may be the extent of coherent growth of particle and matrix, that is the degree of "epitaxy." Particles larger than 0.05 micron are all plate-like. Although X-ray work has indicated that those as small as 300 Å also have this form they appear round in electron micrographs. In another paper the method of formation of the plates of precipitate in aged aluminium-copper alloy from small particles of copper-rich material, which apparently develop upon selected planes, was shown.

Photographs of precipitate in aluminium alloys shown by Dr. Castaing included an exceedingly remarkable picture of 0.78% magnesium, 0.5% silicon alloy which had been aged for 17 days at 150° C. This was a shadowed oxide film replica and showed the precipitate in the form



Photograph due to R. Castaing, O.N.E.R.A. (France)

A shadowed replica of precipitate in an alloy of aluminium with 0.78% magnesium, 0.5% silicon, aged for 16 hours at 250° C. The precipitate is in the form of rods which are clearly oriented parallel to one or other of three mutually perpendicular directions.

of needles protruding from the replica film, all of them parallel to one or another of three mutually perpendicular directions. This print provided a brilliant display of a structural phenomenon which it is almost certain could not have been observed directly by any other means. Dr. Castaing referred to this as "linear epitaxy." In any work on precipitation it is most desirable, as Dr. Guinier stressed, to correlate with electron metallographic studies X-ray diffraction evidence of the first appearance of new phases.

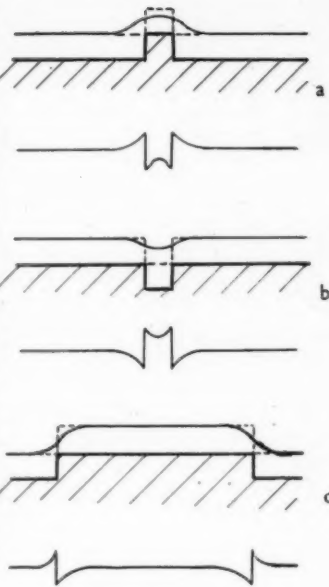
In a study of the stress corrosion of an aluminium—7%—magnesium alloy, the light microscope has shown that after ageing, something, probably β phase, appears along some of the grain boundaries. Electron metallographic studies, by Dr. G. L. J. Bailey and Miss Vernon-Smith, of the electrolytically-polished material, etched in phosphoric acid, show small square pits along these boundaries. From another sample polished mechanically, and also etched, a Formvar replica was obtained having a fin 2–3 Å thick and 2,000–3,000 Å deep, suggesting that the boundary had been etched out to this form. This picture is a most remarkable result and of a type which could not possibly have been obtained by optical microscopy.

Slip

A few years ago Heidenreich and Shockley showed that the slip bands observed normally in pure aluminium are made up of small sharply defined elements of slip. On each of these about 2,000 Å of slip has taken place and they are spaced a few hundred angstroms apart within each band. Although this work became one of the classics of electron metallography the original workers apparently did not follow it up, but Dr. A. F. Brown, of Cambridge has now made further important observations, particularly about the influence of temperature upon this structure. He has found that for any given deformation, that is for a given density of elementary slip lamellae, the bands are fewer in number at high temperatures but each then consists of more lamellae. The effect of further deformation is to increase the number of slip bands, not to alter the number of elementary lamellae in each. Thus, at -180°C . bands consist of one or two elementary lamellae, at room-temperature of three or four, but at 500°C . of about a dozen: the spacing of the bands is less than 1 micron at -180°C ., about 2 microns at room-temperature and about 10 microns at 500°C .

In specimens deformed slowly at high temperatures the slip-bands are curved and, under the electron micro-

Diagram (a) shows the actual form in section of a plastic replica of a surface with a small protuberance: the "ideal" form obtained if a layer of constant thickness were added to the surface is given by the broken line. The curve below shows the corresponding density distribution in a micrograph. Because of the flow of the top surface of the plastic the image of the protuberance will probably have a light rim and a dark encircling band. Diagram (b) shows the similar case for a small pit and (c) the case of a step of large lateral dimension in which case there is no distinction of contrast between the normal and raised areas in a micrograph, but dividing light and dark bands between them.



scope, an explanation is found in the observation that any one lamella is then broken by steps to left or right of its mean direction, these steps lying along the other slip systems. Thus the direction of a lamella can wander and the whole system of a band is completely interwoven.

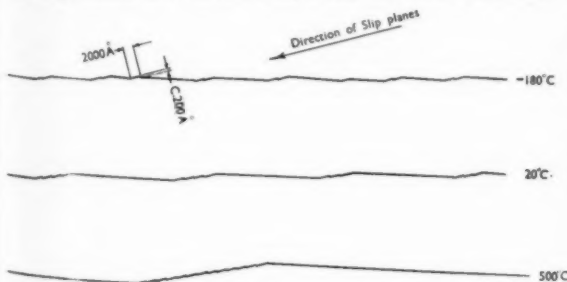
Dr. Brown suggested that the spacing of elementary lamellae of slip may be related to the "orange-peel" or furrow structures sometimes found on replicas of electro-polished aluminium.

Techniques

Much of the interest in techniques was concerned with plastic replicas. It was again pointed out that real replicas of this type differ from ideal ones and that this must be borne in mind when studying micrographs. For example, the micrograph of a specimen with small protuberances would show these with a dark surrounding band, while around pits of small width a light band should appear. Moreover large areas etched to different depths would not be differentiated by different depths of tone in the image, as one might at first thought expect, but would be separated by light and dark bands along their boundary. Such effects have been commented upon since the earliest days of plastic replicas, but their full extent is still not always appreciated.

Studying Formvar replicas of pearlite or sorbite etched in 1% nital, Drs. Nutting and Cosslett found the depth of etch giving the best replica to depend upon the spacing of the lamellae of the pearlite or the carbide particle diameter in sorbite. It appears that for every material a new optimum etching procedure will have to be worked out for electron metallography, and probably a different one for each type of replica.

A method which may become useful was illustrated in papers by Dr. Mahl and by Drs. Cosslett and Nutting: in this, oxide replicas are taken from aluminium which has been pressed into a fractured surface. The great depth of focus of the electron microscope makes it possible to study fractures at high magnifications and the different constituents of an alloy may be seen in the cleavage. A picture showing rather regular steps and



Idealised sections through the surface of aluminium as extended the same amount at a low, normal or a high temperature. The slip bands are built up of much smaller elementary slip lamellae. At high temperatures the bands are widely spaced and each consist of many lamellae: at low temperatures they contain fewer but are closer together.

pits in the fracture of pure iron, broken at -180°C ., was of considerable interest.

In an account of the application of the electron microscope to the study of the particle size of tungsten powders Mr. Morley stated that it would be an extremely tedious task to collect sufficient data for a particle size distribution curve. Nevertheless the general trend of the disintegration on milling is made quite apparent with a moderate amount of work. Another photograph illustrated the rather striking fact that it may be useful to shadow the powder of so dense a metal as tungsten, for this brings out additional information about the form of the particles.

As for the microscope itself, this is now a beautiful commercial product, available in several models, and

almost fool-proof and simple to use. Dr. Cosslett did, however, suggest that manufacturers have not in the past given as much consideration to the requirements of metallographers as might be desired. He pointed out the desirability of an overlap of the magnification ranges of the light microscope and the electron microscope, the magnification of which could usefully run down to 500 diameters.

It is possible that there are still useful applications in the field of metallography for the grazing angle microscope. The peculiarity of this instrument is that no replica is required, but the metal surface is itself examined at an oblique angle. So far only one microscope of this type has been used, that in the Siemens-Halske Laboratory in Germany, but one is now being planned by Dr. Cosslett's Group at Cambridge.

Device for Minimising Rounding of Microspecimens

By A. J. CHISHOLM, B.Sc.(Eng.), A.M.I.Mech.E.*

THE difficulty experienced in preventing "rounding" of the edges of metallurgical micro-specimens during hand polishing on abrasive papers is well known, and a description of a device designed to reduce this tendency and to ease the labour of polishing may be of interest.

The accompanying illustration (Fig. 1) shows the special forked handle which is used. The ends of the fork are inserted into two holes drilled diametrically opposite in the specimen mount, and as close to the face to be polished as possible. A sliding collar on the handle conveniently closes the fork ends so that the specimen is securely held, but is free to rotate.

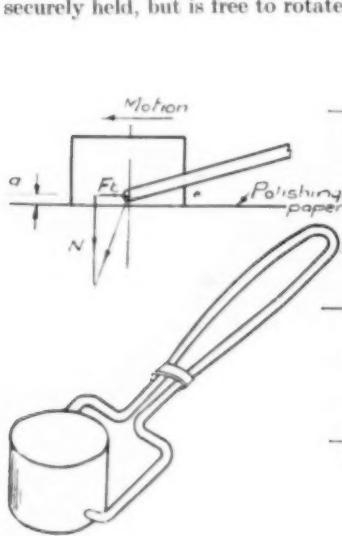


Fig. 1.

This device reduces the tendency of the specimen to round because the tractive effort F_t for moving the specimen over the polishing paper, is applied close to the interface between the specimen and the paper. The couple tending to cause rocking of the specimen is F_t and is, therefore, appreciably smaller than the rocking couple caused when the tractive effort is applied with the finger tips near the top of the specimen mount.

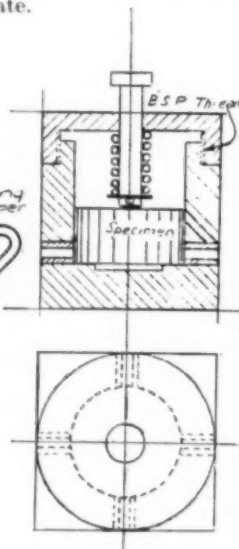


Fig. 2.

Apart from the reduced tendency for rocking of the specimen, the handle reduces the concentrated effort required from the operator.

A jig (Fig. 2) enables the four holes in the standard plastic specimen mount to be drilled quickly and easily.

The Electrolytic Polishing of Tin in Perchloric Acid

By K. E. PUTTICK*

PREVIOUS workers who have polished tin electrolytically have used a mixture of acetic anhydride and perchloric acid recommended by Jacquet.¹ Such mixtures are dangerously explosive and unpleasant to handle, and other methods of polishing tin have been sought. Perchloric acid/alcohol mixtures such as have been used for polishing certain aluminium alloys were tried with little success, and eventually pure perchloric acid was used; in the absence of organic matter it is much safer to handle, and gives a polish at least as brilliant as does Jacquet's solution.

The containing vessel is a glass crystallising dish 15 cm. in diameter. The cathode is a spiral of aluminium tubing, continuously cooled, and the specimen is gripped at the centre of the bath with the face to be polished vertical. It has been found that the best results are obtained when the anode is rotated about a vertical axis; the specimen for which this particular technique has been developed is about 2 cm. \times 0.5 cm., and is held by an aluminium clamp attached to the spindle of a stirring motor (from which it is insulated by a fibre sleeve). Electrical contact to the revolving clamp is made by a brass collar and brush. As stirring increases the critical current density, a low rate of rotation (60–100 r.p.m.) is used. The D.C. supply is from a 210 v. source, controlled by a potentiometer.

The 60% aqueous "Analar" solution is quite satisfactory for the purpose. When the electrolyte is fresh the critical current density is about 40 amp./dm.² but increases gradually over a period of weeks as more tin is dissolved. When the current density becomes inconveniently high the acid can be reclaimed by the following procedure. Concentrated nitric acid is added (one-third to one-half the volume of the solution) to minimise any danger arising from the presence of organic materials. The mixture is then allowed to stand at about 80°C. until the volume is reduced to somewhat less than the

* Royal Aircraft Establishment, Farnborough. This note is published by permission of the Chief Scientist, Ministry of Supply.

1 Jacquet, P. A., The Electrolytic Polishing of Tin. Tech. Publ. Int. Tin Res. Council No. 90 (1939).

* Formerly of the Dynamics Laboratory, Metropolitan-Vickers Electrical Co. Ltd.

initial volume of old solution. This usually takes a day or two to complete. The tin is precipitated out in the form of a white solid, probably metastannic acid, which is separated out by filtering through a sintered glass crucible, or by centrifuging.

The polishing action is very rapid, a high degree of polish is obtained in 10-15 seconds, though if the original condition of the surface is very rough it may be necessary to polish for longer. As with Jacquet's and other electropolishing solutions of perchloric acid, a thin solid film is often observed to form and peel off the specimen at the beginning of the process, especially if it has been long exposed to the air.

New Laboratory Equipment

Quick-Acting Recorder

THE new Cambridge quick-acting pen recorder has an exceptionally high response speed (approx. 0.5 sec.) which, coupled with the many advantages of the continuously self-balancing method employed, makes it suitable for accurately recording rapidly changing magnitudes of phenomena which can be translated into electrical voltage or resistance change. The charts, which are 180 mm. wide, are ruled to suit the particular application.

The recorder pen is coupled to the variable arm of a measuring network, such as a resistance bridge or potentiometer, continuously maintained in balance by a servo system actuated by the unbalance voltage occasioned by any variation in the quantity measured. The D.C. error voltage from the measuring potentiometer or bridge is chopped by means of a vibrating reed commutator. The resulting A.C. voltage is amplified and applied to a phase conscious twin rectifier system which modifies the current balance in a pair of contra-rotating magnetic clutches which in turn drive the recorder towards balance. Damping of the pen movement is achieved (depending on the range and application) either by a passive phase advance network or by means of an auxiliary slide wire system which injects a voltage proportional to the pen velocity into the error circuit.

The apparatus derives its power from the A.C. mains and is unaffected by the normal variations of supply voltage and frequency.

The chart is driven by a synchronous motor and passes over a flat plate giving support to the paper when notes have to be added to the record during a test. Single chart speeds of 0.5, 1, 2.5 or 5 in./min. are normally provided, but in certain cases speed-change mechanism can be fitted. One arrangement which is sometimes useful provides a high speed of say, 2.5 in./min., together with an idling speed of, say, 5 in./hr., controlled by a lever. In all instruments a switch is provided for stopping the recorder and chart mechanism, whilst leaving the detector amplifier energised so that recording may be immediately restarted.

Where variations in the recorded quantity have to be correlated with other phenomena, provision can be made for marking the chart at any instant.

Generally the detector sensitivity is such that accurate rebalancing will be obtained provided that the measuring system produces a voltage of not less than 1 mV. for full-scale unbalance and the circuit resistance does not exceed 2,000 ohms. If a greater unbalance voltage is available the circuit resistance can be increased.

The rate of dissolution is very high, about 0.3 gm. of tin per minute. The process is thus very useful for quickly removing the surface layers of a specimen without mechanical deformation in order to examine the structure at different levels. The grain boundaries are delineated during the polishing.

Lead has also been successfully polished by this method; the conditions have not been fully investigated, but the best results so far have been obtained when the face to be polished is held horizontally, just below the surface of the liquid and a higher rate of rotation and current density used than for tin.

Recorder networks so far employed fall into the following three general types, but each has many variants and other general forms are possible.

(a) *Recording Potentiometers*.—These may be single or multi-range and calibrated in terms of voltage, current, temperature, light intensity, etc. They are normally standardised in terms of a standard cell voltage, all necessary controls being included in the instrument. The potentiometer current is normally supplied from a dry cell.

(b) *Resistance Bridges*.—These may be either single- or multi-range, calibrated in resistance, temperature, strain, etc.

(c) *Ratiometers*.—These recorders measure simply the ratio of two variables which can be applied to the instrument in the form of two voltages or currents. The measuring circuit is a potentiometer, the denominator variable being the slidewire current in terms of which the numerator voltage is measured. The pen position at balance indicates the ratio of the two quantities irrespective of their absolute magnitudes.

The Cambridge Instrument Co., Ltd., 13, Grosvenor Place, London, S.W.1.

Electronic Frequency Meter

THE need for measuring frequencies in the range 0-20,000 c.p.s. arises in almost every industry, whether the application is concerned with mechanical effects, such as tachometry, or vibration studies, or in acoustic and audio work. The Airmec Frequency Meter (Electronic Tachometer) Type No. 726 is designed to satisfy this need. Based on electronic principles it is inherently static and, having no moving parts to wear, is reliable and robust. In electrical and audio work the voltage source of the frequency can be applied directly to the input of the instrument, but in the case of mechanical effects such as vibrations, it will be necessary to convert the effect into an equivalent voltage change by the use of any of the usual electro-mechanical pick-up devices.

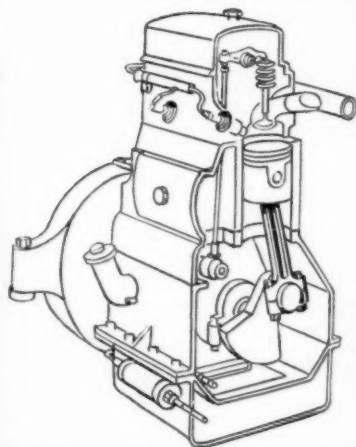
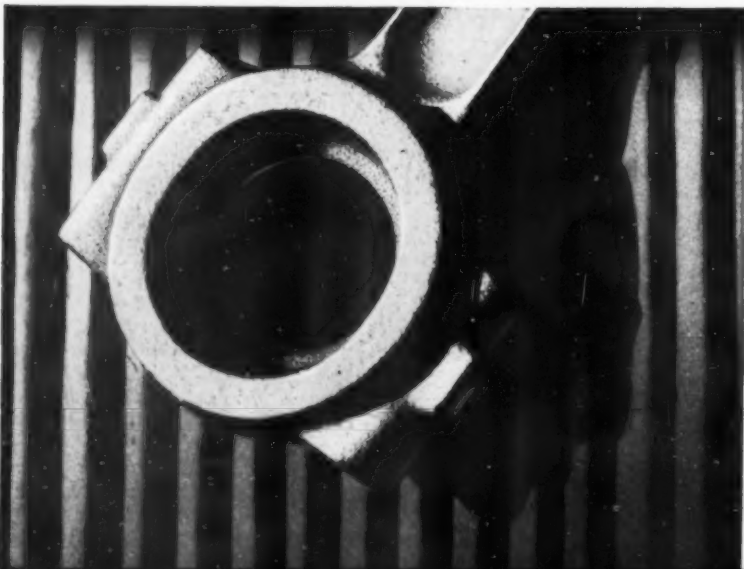
The instrument has three frequency ranges, 0-200; 0-2,000; and 0-20,000 c.p.s. and has a reading accuracy of $\pm 1\%$ of full scale. The input voltage may be 0.1-20 v. peak to peak and the waveform may be of any contour, provided that it does not pass through zero more than twice every cycle. Models suitable for 100-130 v. or 200-250 v. 50 c.p.s. A.C. supplies are available and mains voltage variations of $\pm 10\%$ do not affect the accuracy.

Airmec Laboratories, Ltd., Cresser, High Wycombe, Bucks.

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S M E T H W I C K A N D K I D D E R M I N S T E R E N G L A N D

Creep Test Control and Furnaces

THE resistance thermometer controller manufactured by Sunvic Controls, Ltd. has found wide application in the creep-testing field. As a result of recent developments it is now possible to purchase the complete electrical equipment for a creep-test unit—comprising furnace, control panel and resistance thermometer—from the same source. The user is thus relieved of any anxiety as to the performance of the apparatus, since the whole is designed with the object of securing maximum reliability and accuracy.

The resistance thermometer can be supplied in three standard lengths, namely, 6 in., 9 in. and 11 in., the element being constructed of pure platinum with gold lead-in wires. At 0°C. the resistance is $10\ \text{ohm} \pm \frac{1}{2}\%$ and tests carried out over a period of 1,500 hours at 700°C. indicate that the stability is better than 0.1%. For higher temperatures than this, a special thermometer can be supplied.

The furnace control panel has been designed to operate in conjunction with the Sunvic creep-test furnace and has provision for the adjustment of the mean power input by means of a variable voltage transformer, adjustment of the switching voltage and two shunt resistances for the correction of the temperature gradient on the specimen. The equipment fitted to the panel includes a resistance thermometer controller, a 15-amp. main switch fuse; a 3 kVA. Berco Regovolt transformer, an increment resistor value $3 \times 3\ \text{ohms}$; two shunt resistors value 60 ohm 2 amp.; and an ammeter scaled 0-15 amp.

One of the essential conditions to be met by a creep-test furnace is that the temperature gradient shall be a minimum. This is effected by the use of four windings brought out to five terminals at the top of the furnace which can thus be used as a 2, 3 or 4 zone unit. For normal purposes the centre windings are used as a single winding. It will be appreciated that the gradient will vary with differing operating temperatures and provision is made on the control panel for two shunt resistors for this purpose. The refractory tube is of Vitreosil of I.D. $3\frac{1}{2}$ in. and length $16\frac{1}{2}$ in. The sheet-steel furnace casing is filled with Amberlite 12/2 insulating powder and has lugs fitted to the top and bottom plates for locating the furnace on the Denison Type T45 creep-testing machine.

Sunvic Controls, Ltd., 10, Essex Street, Strand, London, W.C.2.

British-Made Thermocouple Alloys

AFTER research within their own organisation and in industry, the British Driver-Harris Company have now succeeded in producing two new thermocouple alloys for high-temperature measurement. These products, T1 (nickel-chromium) and T2 (nickel-aluminium), are similar to those widely used in industry for many years, made of materials imported principally from dollar sources. The British Driver-Harris T1 and T2 alloys, however, are manufactured throughout at the Company's factories at Manchester and Cheadle Heath. It is particularly gratifying to note that there has been no increase in the price of these two alloys due to the recent devaluation of sterling.

We understand that these new British-made alloys will operate at the same temperatures as those usually covered by similar imported materials, the thermal E.M.F. values following the same general curve.

Book Review

THE INSTRUMENT MANUAL, 1949

By several authors: 1949, VII + 548 + CXIII pages, fully illustrated; published by United Trade Press, Ltd., 24, Bride Lane, London, E.C.4; price 70s.

THE importance of instruments in the progress of scientific knowledge, in the quantity production of goods of many kinds, and in the maintenance of a uniform standard of quality, is not yet sufficiently appreciated by industry; indeed, their importance is not fully appreciated by many technicians and scientists. The latter reflection is probably due to the attention being directed to the results achieved, whether in the laboratory or in industry, rather than on the instruments used to obtain them. In some cases remarkable results are obtained with very inferior tools, but, as a rule, more uniform results of a high order and greater achievements are obtained the better the tools or instruments, provided they are used to the best advantage, and this book provides in convenient form, information on available industrial instruments designed to facilitate observation, make measurements, record data, and manually or automatically control processes.

This book gives a comprehensive survey of the great range of instruments in general use; data frequently needed; details of relevant literature; names of suppliers; a dictionary of manufacturers and organisations directly interested in the subject; and periodicals dealing with current instrumentation problems. It can be regarded as the most comprehensive work on the British instrument industry. It is divided into some 21 sections, dealing respectively with: engineering precision instruments; engineering and mechanical instruments; optical instruments; instruments for the determination of texture; instruments for the determination of compositional quality; measurement and control of time and speed; measurement and proportioning of weight; measurement and control of pressure; measurement and control of level; measurement and control of specific gravity; measurement and control of temperature and pyrometers for furnace temperature; measurement and control of flow; measurement and control of hydrogen ion; measurement and control of humidity; automatic control; electrical measuring instruments; review of electronic instruments; general trends in instrument design; organisations interested in instruments; publications directly associated with instruments; dictionary of manufacturers; and a useful index. All the sections are sub-divided and are written and compiled by practical men with an intimate knowledge of their respective branches of the industry and the type of information generally required by users and potential users of instruments.

In the treatment of each section it is noteworthy that the newer apparatus and techniques are given in more detail than those fairly well known. An important addition to each section is a selected bibliography of literature on the subject published during the last decade.

In the present economic condition of this country, when the need for quality and low cost products is of primary importance, there is no main feature that is not dependent in some form, on instruments; they are now the eyes and ears of all progressive industries; we depend on them for the satisfactory supply of gas, electricity, water, the transportation of food and, indeed, almost

every service concerned with industry involves the use of instruments, and this book will be invaluable to all concerned with industrial instruments, whether they be manufacturers or users, particularly as a work of reference.

B.S.

Modern Developments in Metal Finishing

A COURSE of lectures on Modern Developments in Metal Finishing will be held at the Northampton Polytechnic, St. John Street, London, E.C.1, commencing on Wednesday, January 11th and continuing on successive Wednesdays until March 1st. A list of the topics covered, together with the names of the lecturers, is given below.

"Recent Developments in Electrodeposition Processes," by E. A. Ollard, F.R.I.C., F.I.M. (British Non-Ferrous Metals Research Association).

"Recent Developments in Plant for Electrodeposition," by E. A. Ollard.

"Phosphate Treatments for Iron and Steel Surfaces," by H. A. Holden (The Pyrene Co., Ltd.).

"Methods for the Protection and Decoration of Aluminium," by V. F. Henley, B.Sc., F.R.I.C. (W. Canning & Co., Ltd.).

"Methods for the Protection of Magnesium Alloys," by W. F. Higgs, Ph.D. (Magnesium Elektron, Ltd.).

"The History and General Principles of Vitreous Enamelling," by W. E. Benton, M.Sc. (S. Flavel & Co., Ltd.).

"Vitreous Enamels, their Compositions and Methods of Application," by S. Hallsworth (Metal Porcelains, Ltd.).

"Vitreous Enamels and their Value in Industry," by H. Laithwaite, M.Sc. Tech., A.R.I.C. (Radiation, Ltd.).

Admission to the course, for which the fee is 15s. is effected by personal enrolment at the Polytechnic Office, any day from 10 a.m. to 7 p.m., or by post.

Oertling Staff Meeting

A MEETING was held by L. Oertling, Ltd. on November 24th and 25th, at which all area service representatives were present, together with works personnel and the sales staff at Gloucester Place.

The meeting was opened on the first day by Mr. J. Rock Cooper, Oertling's chairman, who expressed his appreciation of the close liaison maintained with the men "in the field" and emphasised the necessity for continuing and if possible increasing this co-operation in order to provide the best possible service to balance users. It was only by a proper understanding of the chemists' needs and difficulties that the design staff could produce balances of the required performance.

The first day's session ended with a dinner for all concerned and a visit to a London theatre.

Among the senior members of the Company present were: Mr. H. Ley, works manager; Mr. M. Cox, secretary; Mr. J. R. Waite, sales manager; Mr. C. Hannon, assistant sales manager; Mr. V. Wallis; and Dr. G. F. Hodsman, in charge of research.

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